The Innovation Hub
for Affordable Heating and Cooling

Integrated Design Studios Document

Sub-tropical Mixed-use Buildings

IDS 13 Knowledge Sharing Report (100% Milestone 7)

V1 – 27 May 2022

Queensland University of Technology

About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry’s transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

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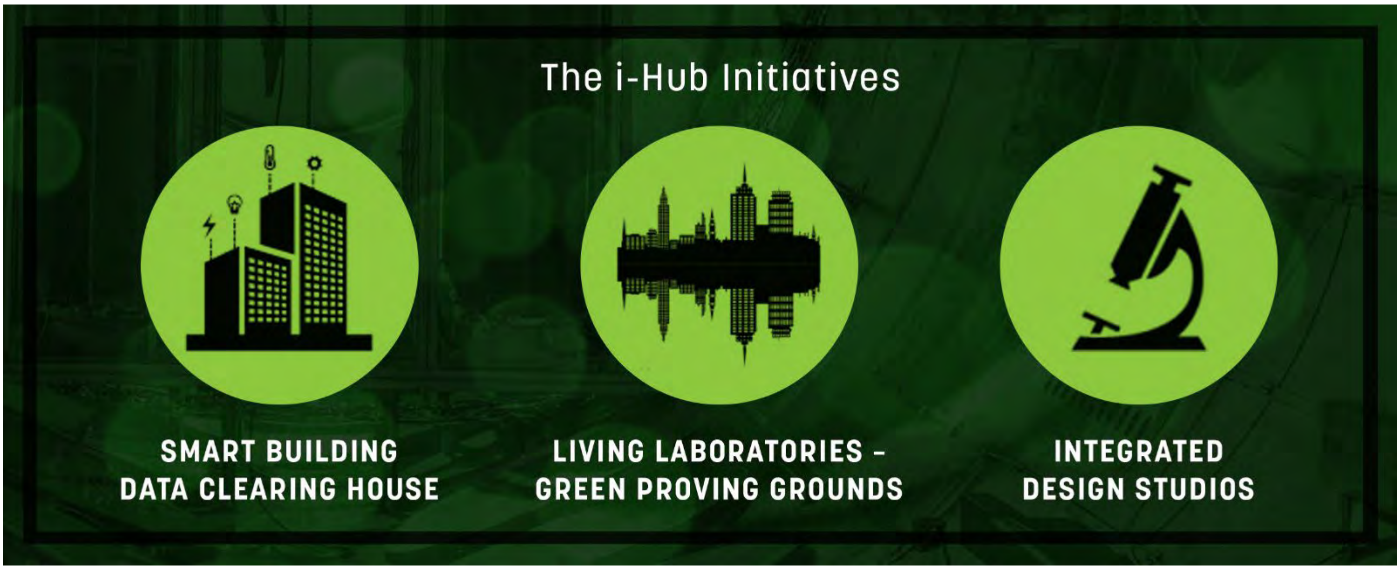

i-HUB Design Studio 13 Final Report (100% Milestone)

The Sub-tropical Mixed-Use Building Integrated Design Studio (IDS 13), investigates design innovation in a mixed-use building typology that incorporates aged care. The climatic context is sub-tropical Caboolture (south-east Queensland). The objective is to reduce net energy consumption through passive and active measures (e.g. the use of renewables and other energy technologies), whilst at the same time addressing the needs of different building occupants (including the elderly) and the whole-of-life focus of the client (Bolton Clarke). Over a period of 2 semesters (March – November 2021), a group of architecture and non-architecture students (mechanical/electrical engineering and construction management) worked with architecture, engineering and sustainability experts and the client to develop design solutions for this context.

High energy use in aged care facilities is attributed to their 24/7 operation, with a considerable portion of energy use attributed to space heating and/or cooling. The sub-tropical climate of Caboolture presents challenges in the design of buildings (passive design and materials selection); in the selection, design and operation of heating and cooling technologies; and in the utilisation of renewable energy and associated technologies to manage peak demand and greenhouse gas emissions.

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Contact name	Wendy Miller		
Position in organisation	Associate Professor, School of Architecture and Built Environment		
Phone	0401 771 062	Email	w2.miller@qut.edu.au

Report Contributions

Name	Organisation	Report section
A/Prof Wendy Miller	QUT	Main author
Dr Aaron Liu	QUT	Section 3.2.3
Andrew Williams Amir Tabadkani	Stantec	Section 3.2.4
James Robertson	QUT student – electrical engineering	Section 3.2.3
Zia Sabdia	QUT student – construction management	Section 3.2.1
Wing Yee Wiener Leung	QUT student - architecture	Section 3.2.2, Fig 2-1, Fig 3-3, Fig 3-6
Tala Clewes	QUT student - architecture	Fig 3-2
Hung Yi Kuo	QUT student - architecture	Fig 3-5
Angus Smith	QUT student - architecture	Fig 3-1, Fig 3-7
Tibby Tian	QUT student - architecture	Fig 3-9
James Mantis James Chiou	Bolton Clark	Site information, design feedback
Mark Trotter Paul Trotter	Fulton Trotter Architects	Design feedback
Lindy Burton Naima Iftikar	QUT	IDS Initial evaluation

IMPORTANT NOTE: IDS13 and IDS14 were run concurrently, with the same client and industry consultants. This Knowledge Sharing Report and the equivalent IDS14 report contain some common information, in particular Section 2 (relating to learnings about mixed-use building typologies) and Section 4 (evaluation of the integrated design process). In addition, Appendix A of this report contains information that was in the previous 50% report for IDS13 (i.e. a detailed description of the IDS 13/14 program and observations). This is repeated, with some editing, for completion purposes (so that all IDS 13 information is contained in the one report).

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1 EXECUTIVE SUMMARY

The objective of the suite of integrated design studios conducted through the iHUB was to develop an enhanced understanding of the integrated design process and outputs, and its industry application. This specific IDS focused on a mixed-use building, incorporating aged care, in the subtropical location of Caboolture. Undertaken concurrently with IDS 14 (tropical mixed-use buildings) in 2021, the combined studio involved 26 Master of Architecture students; 2 electrical engineering students; 1 mechanical engineering student; 3 construction management students; 6 industry consultants (mechanical engineering, energy modelling professionals, civil and environmental engineering, and construction management); 7 industry/academic professionals (architecture, architecture pedagogy, integrated systems, electrical engineering, architectural engineering); and client representatives (asset manager and project manager for Bolton Clarke). As the client for both contexts was a vertically integrated company that develops, owns and operates aged care facilities, design requirements included consideration of whole-of-life (WOL) aspects and total-cost-of-ownership (TCOO) as well as net zero energy (NZE) and net zero carbon (NZC) considerations (encompassing the concepts of passive design to minimise space heating and cooling loads, selection of efficient and controllable space heating and cooling technologies, and the application of onsite renewable energy generation). The key findings from this process, relevant to the subtropics, are presented here.

1.1 Mixed Use Buildings – challenges for NZE

Mixed-use building typologies present a number of challenges for achieving net zero energy, such as:

- There is no ‘business as usual’ (BAU) energy use intensity (EUI) data for this building typology. BAU estimation requires obtaining average EUI data for each of the building classes expected to be incorporated into the mixed-use building.
- Spaces within a mixed-use building can be used for different purposes (and by different classes of buildings) over time, so measurement of energy performance against BAU becomes even more problematic.
- There is no clear methodology for allocating energy consumption and generation data (whole and parts) for a mixed-use building, making it difficult to assign energy consumption costs, renewable energy generation benefits and demand response capabilities (who pays, who benefits, who decides?). It also presents challenges for the setting (and meeting) of net zero carbon or net zero energy goals (e.g. does it relate to all tenancies, or just common areas? Who decides on the target?).
- Mixed-use buildings that incorporate residential services present a unique problem in that the building is both a home and a workplace, creating additional challenges relating to HVAC technology selection, system sizing, design and operation.

1.2 Proposed technology solutions and evaluation

The key technologies investigated in this IDS, and their indicative benefits, are summarised in Table 1-1. Note that these indicative savings are based on the specific assumptions for each of the feasibility assessments. It should also be noted that technology solutions examined for IDS14 (for the tropics) and for other IDS projects (in temperate climates) may also be suitable for the subtropics and for this mixed-building typology.

Table 1-1 Examined technologies and their impacts

Technology	Indicative demand reduction potential (compared with BAU)	Renewable Energy Potential	Co-Benefits
Vertical Green Systems	20-44% reduction in cooling energy	Would increase the % of load met by PV	Increase thermal comfort; health and environment benefits; dementia benefits
Adaptive Design	-	-	Lower embodied energy over life of the building
PV + Battery with Supercapacitor	Potential to participate in demand response markets	360kWp could meet NZE (for this case) 8*50kWh battery storage could be beneficial	
Parametric design – for materials selection	>10% reduction in cooling demand	Would increase the % of load met by PV	
Parametric design – for natural ventilation and control strategies	A process to enable quantification of reduction in cooling load		33% increase in indoor comfort Potential for optimal performance outcome within the cost parameters required

1.3 Application to industry

Five key factors, interrelated and interdependent, were identified as being important to successful outcomes from an integrated design process:

- A client brief that is open to being developed through the integrated design (ID) process, rather than pre-established
- A recognition of all participants, irrespective of profession, being equal co-designers, and a new or specialist role of integrated design facilitator or systems integrator.
- An early process whereby all participants gain an understanding and appreciation of each profession’s language and design processes
- A range of communication strategies to capture different skills and methods used by the team
- A whole-system thinking approach that, from and energy perspective considers the building, its services and technologies, and the energy systems that power it; as well as the human systems that inhabit the building and the climate in which the building and humans exist. It reaches beyond energy performance outcomes, but looks for multiple benefits from single solutions

The implementation of integrated design will require a suitable procurement instrument. The ID process is not well served by traditional procurement contracts (e.g. design and construct D&C), or even collaborative procurement contracts such as early contractor involvement (ECI). Integrated Project Delivery contracts appear more suitable, as they establish individual and group accountability. All parties accept, manage and share design and construction risks. Financial risks and rewards are shared through an agreed profit/incentive pool based on quantifiable project outcomes. An Alliance Contract is one such IPD contract type. An alternative contract type, suitable for integrated whole-life delivery projects, may be a Design-Build-Operate (DBO) contract. Refer to Table 4-1 for more information.

A proposed set of IDP Design Principles for NZE has been developed, based on Rocky Mountain Institute's Factor 10 Engineering Design Principles. This set of principles is proposed as a starting point for companies wishing to engage in integrated design. Refer to Section 4.2.2 for more information.

Table 1-2 Integrated Design Principles for Net-Zero Energy Buildings

Design phase	Integrated Design Principles for Net-Zero Energy Buildings
Before design starts	Establish a clear, shared, ambitious NZE goal and timeframe for achieving that goal. Consider including other related goals, such as resilience, adaptation, grid autonomy. Determine KPIs that reflect the goals, including ambitious energy efficiency.
	Convene a transdisciplinary design team (e.g. engineers, architects, construction contractor, building owner/manager/occupants, ID specialist/facilitator) with diverse skills and experiences.
	Avoid the linear march through traditional design phases (project objectives and aspirations; design concept development; master planning; design development; feasibility evaluation). ID is iterative, with successive stages informing earlier ideas.
	Implement an Integrated Project Delivery contract that rewards teams for meeting KPIs and providing savings, rather than producing documents.
Focus on the right problem	Understand the purpose of the building and the needs of the people who will occupy it. What energy services will be required and what environmental, regulatory, technical and social contexts are likely to exist over this period?
	Push past end-uses (e.g. HVAC), resulting services (e.g. comfort) and ultimate benefits (e.g. health, productivity) to understand the full range of ways to fulfill the purpose/s.
	Take a whole-of-life approach to designs and their consequences (i.e consider current and future occupants and environmental context).
	Establish BAU benchmarks for the KPIs, and whole-system, lifecycle value of savings (e.g. in kWh, kW, CO2e, HVAC kVa, PV kWp etc)
	Use science and the plethora of simulation and modelling tools available to determine the theoretical minimum amount of energy needed to provide the energy services (especially HVAC). Consider how far each practical design constraint (e.g. cost, safety, performance, accessibility) moves away from that theoretical minimum.
Design Integratively	Don't start with a familiar or previous design or conventional assumptions or methods. Start afresh with no preconceptions.
	Question all rules of thumb and assumptions. Require all proposed design options to demonstrate performance against the KPIs.
	Establish a hierarchy of approaches: super energy efficient building envelope (design and materials), building services (technologies and controls), and renewable energy (generation, storage, control). This will produce compounding savings upstream.
	Simplify systems and components, valuing passive solutions over active solutions wherever possible
	Think beyond current benefit:cost evaluations and minimum performance standards. Incorporate whole-of-life, total cost of ownership, and non-monetary value evaluations
	Create enhanced value by ensuring each part, subsystem or system provides multiple benefits.
	Optimise energy systems to meet the diverse annual conditions (use and generation), and implement control strategies to minimise or shift peak demand and optimise self-consumption
	Incorporate technologies (e.g. integrated BMS, EMS) and processes (e.g. post occupancy evaluation) to inform design success and future designs.

2 MIXED USE BUILDINGS

This section discusses the definition of mixed-use buildings, the options presented through the IDS process, and the challenges that this building typology faces with regards to energy system design and operation.

2.1 Defining mixed-use buildings

This Integrated Design Studio (IDS14) and its companion IDS13, focused on mixed-use buildings in subtropical (IDS13) and tropical (IDS14) locations. Mixed-use buildings are buildings that have more than one classification according to the National Construction Code[1]. In the case of these studios, a key requirement was that the design needed to include an element of aged care (Class 9c; for example independent living units (ILUs – no care), assisted living units (ALUs – low/medium care), supported living units (SLU – medium care) or residential aged care (RAC – high care)). Other residential types were not excluded (e.g. apartments, Class 2). There were no restrictions on other building classes (e.g. offices (class 5), retail (class 6), education and public assembly (class 9b)) so long as it could be argued that proposed building uses would not adversely affect the living requirements of elderly persons. It was presumed that most building designs would include car parking (Class 7a).

As the client is a vertically integrated company that develops, owns and operates aged care facilities, additional requirements included consideration of whole-of-life (WOL) aspects and total-cost-of-ownership (TCOO). Net zero energy (NZE) and net zero carbon (NZC) were additional considerations, encompassing the concepts of passive design to minimise space heating and cooling loads, selection of efficient and controllable space heating and cooling technologies, and the application of onsite renewable energy generation. Onsite energy storage was optional.

2.2 Mixed-use options presented

The development site for IDS 13 is within the campus of Fernhill Aged Care facility, in Caboolture's CBD. The site borders King Street (the main street of Caboolture) and George Street. The immediate neighbourhood includes a shopping centre and assorted retail stores, school, and professional and government services. Refer to Sections 6.1 and 6.3 for site details and aspects of the client brief.

The mixed-use building design options presented through the IDS process are shown in Table 2-1. These options demonstrate alternative approaches to those currently applied to aged care facilities, in particular options for multigenerational living and greater utilisation of facilities by the surrounding community (i.e. blurring of perceived or actual boundaries between senior living facilities and the broader community).

Table 2-1 Mixed-Use building solutions proposed for Caboolture

Mixed use proposals for Caboolture
Mixed use residential, with adaptable internal layout
Multigenerational residential (student units + ILUs)
Mixed retail, allied health, community centre, ILUs
Market Square, student accommodation, child care, ALUs
Café and ILUs
Medical offices, community spaces, retail, ALUs, respite care
Community facilities, retail, SLUs
Mixed retail and ILUs
Mixed retail, allied health, student accommodation, ILUs

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[1] Refer to NCC 2019 Volume One Part A6 Building classification, especially A6.11 Multiple classifications.

An example of the complexity of ‘what is a mixed-use building’ is seen in Figure 2-1, demonstrating variations in the needs of occupants (between social and private functions) and types of occupants. The challenges associated with this building typology, from an energy perspective, are discussed in the next section.

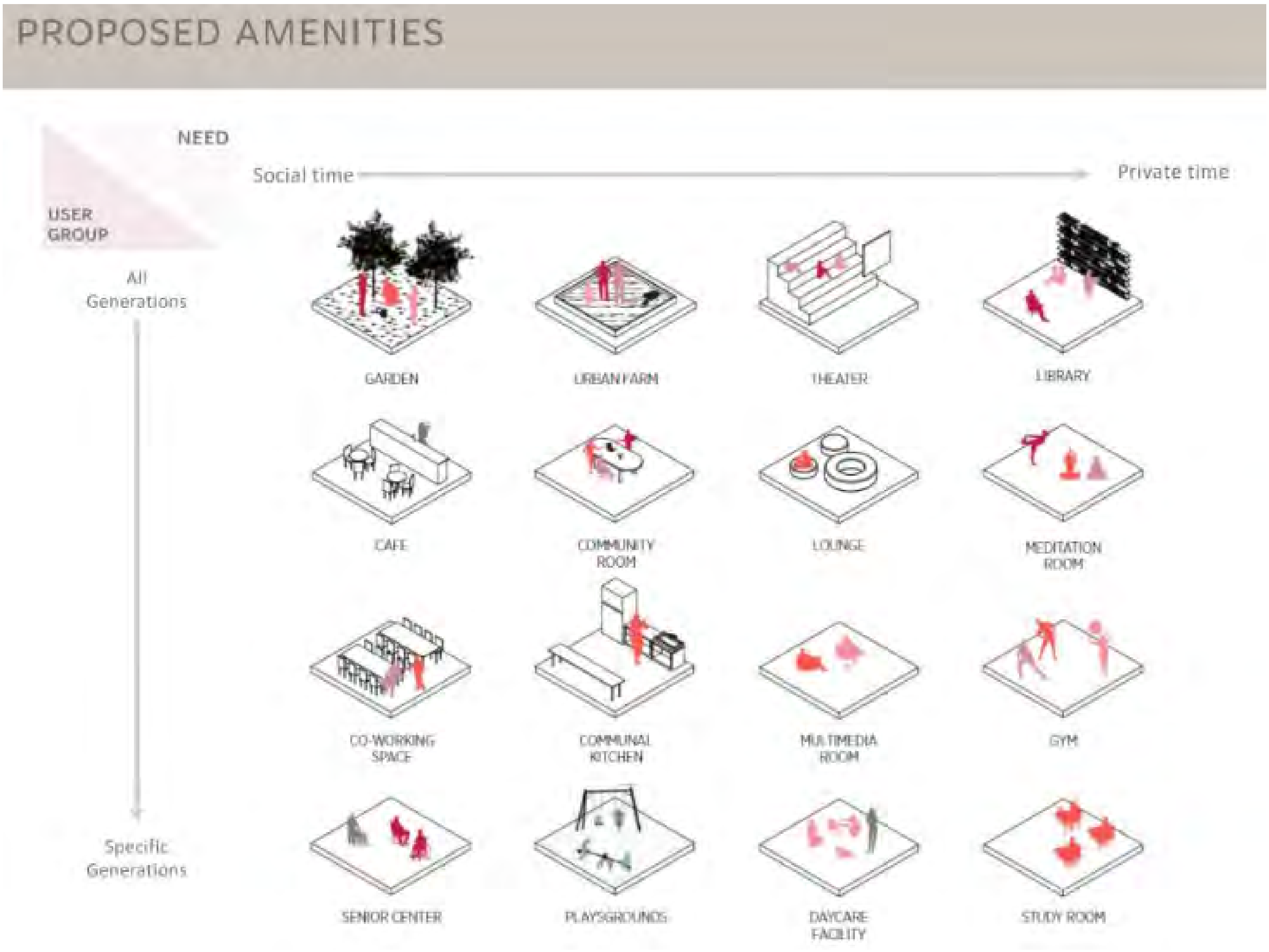

Figure 2-1 Proposed mixed-use amenities - Designer Wing Yee Wiener Leung

None of the designs included an assessment of the economic viability of the various mixed-use tenancies proposed (this was out of scope of the studios).

2.3 Energy challenges for mixed-use buildings

As a building typology, mixed use buildings present some unique challenges relating to designing for net zero carbon / net zero energy. These challenges[2] include:

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[2] Some of these issues were raised in *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia: Part 2 – Appendixes*. November 2012. Council of Australian Governments (COAG) National Strategy on Energy Efficiency, while others have been observed in mixed-use buildings incorporating aged care.

- To determine the building's energy needs and hence design appropriate energy systems**, there is a need to have reasonably robust energy use intensity (EUI) data** (e.g. kWh/m^2/year) for each of the building classes, before design begins. This can be problematic for a number of reasons:
    - There is no baseline energy use intensity(EUI) for mixed use buildings as a typology. (For this IDS, an EUI of 20kWh/bed/day was used, as this is somewhat representative of EUI for aged care facilities in the region.)
    - There are different classification systems assigned to buildings at the design, construction and/or certificate of occupancy stages, for example ANZSIC (economic classification), ABS (functional classification) and NCC (classification impacts, for example, structural, safety and energy performance requirements).
    - Building functions can change over time, as can the nature of occupants.
    - Even within one class (e.g. NCC Class 6 retail) the EUI can vary greatly, for example fast food outlets and supermarkets have much higher EUI than retail stores such as pharmacies, florists, gift shops, hair dressers etc (the types of retail you could envisage co-habiting with residential aged care).
    - Asset owners within one sector (e.g. education) can have different ways of calculating EUI (e.g. what is/isn't included as an education activity)
    - Some spaces in a mixed-use building may be used for different purposes at different times (e.g. may be Class 9b education/TAFE training during office hours, and recreation use by residents after hours / on weekends (nominally class 9c)). Conversely some activities, such as TAFE training, or medical services, may occur in spaces of a mixed-use building that are not specifically classified for that purpose (e.g. in resident rooms or in the communal gym).
    - Some spaces that would be classified as 9c in a residential aged care facility (e.g. allied health / medical practitioner treatment rooms) may need to be classified differently (e.g. Class 5) if the services provided are open to non-residents.
- **There is no clear methodology for allocating energy consumption and generation data in mixed use buildings**.
    - This creates challenges for assigning energy consumption costs, renewable energy generation benefits and demand response capabilities (who pays, who benefits, who decides?).
    - It also presents challenges for the setting (and meeting) of net zero carbon or net zero energy goals. For example, is a NZE goal related to the whole building (including all tenancies), just the common areas of the building, or the common areas and residential areas?
- **Mixed use buildings that incorporate residential services present a unique problem in that the building is both a home and a workplace.** This creates challenges relating to HVAC technology selection, system sizing, design and operation in particular:
    - Different thermal comfort needs and expectations of occupants – between elderly and not elderly; between sedentary and active occupants (metabolic rate); between expected level of personal control (adaptive capacity and personal preferences); and in clothing levels (e.g. sleeping and casual 'at home' clothing levels; casual clothing for common areas; work uniforms).
    - If mechanically cooled or hybrid mode (passive and active cooling), there are challenges in designing a system to meet the diverse needs and determining hierarchy of needs (e.g. who gets to decide the design parameters, the operational parameters, the comfort parameters?) Are industry standards and practices (e.g. ASHRAE 55 or NCC Section J DTS or reference building) appropriate for mixed-use buildings?

3 EVALUATION OF DESIGN SOLUTIONS

This section reports on the qualitative and quantitative evaluation of design solutions proposed for a mixed-use building (incorporating some element of aged care accommodation) in subtropical Caboolture, Queensland.

3.1 Initial evaluation of design solutions

Eleven design solutions were presented for the Caboolture site. Initially these designs were evaluated qualitatively by 'experienced' design professionals (academics and consultants), using a 5 point Likert scale (1 = very little; 5 = a lot) to determine the extent to which each design met each of 8 design parameters, as shown in Table 3-1.

Table 3-1 Parameters for qualitative evaluation of design solutions

Design parameter	Explanation
Client needs	Whole of life cost and value
User needs	Health, wellness, connectivity (of residents and other users)
Climate responsiveness	Understanding of key climate conditions (e.g. seasonal temperature, humidity, solar radiation, wind speed and direction)
Mixed use typology	Appropriateness and diversity of classifications
Building services integration	Cooling load, HVAC technology and controls, energy demand, peak demand, energy and load management options, renewable energy potential
Innovation and creativity	
Codesign, integrated design	Extent to which there is evidence of integration of building services and energy issues within the overall design concept and solution
Evidence of performance outcomes	Evidence of using simulation or … tools to quantify internal conditions, HVAC loads, PV output etc…

In general, design solutions addressed client and user needs and mixed-use typologies reasonably well (scores of 4 or 5, excluding energy issues). Climate responsiveness was not addressed well by many designs (scores 1-3) and building services integration and codesign were also poorly demonstrated (scores of 1-4). Aside from some basic PV system sizing and output calculations, very few design solutions presented evidence of validation / analysis of performance outcomes (in relation to energy use, indoor conditions, HVAC loads, peak demand etc).

These early-career architects were quite adept at traditional architecture response to the client brief (e.g. site context, connectivity, form, detailed resolution of design drawings) but much less knowledgeable about, experienced in, and hence confident to include, aspects that impact on energy performance indicators. This included, in particular, limited or simplistic demonstration of:

- An understanding of the seasonal and diurnal path of the sun, and design responses to control solar radiation into the internal spaces (e.g. shading, window to wall ratio, sizing and placement of windows)
- Site wind speed and direction, and strategies to enhance natural ventilation/cooling and reduce unwanted wind
- Building physics (e.g. properties of materials, such as Uvalue, solar absorptance/reflectance) and the impact this has on internal heat gain/loss, and hence thermal comfort, HVAC technology options and energy use (consumption (kWh) and demand (kW)
- Evaluation methods and tools that could be used to quantify performance

Similarly, the early-career engineers and construction professionals were proficient in applying standard industry methods, but less experienced in exploring non-standard methods or solutions.

In fairness to these early-career designers, however, this was their first experience in integrated design, and it was presented at the end of their training (when they had specific output requirements not directly related to IDS. For example, the early career architects were expected, within a 15 week period, to develop the design and present detailed design drawings for a complete multi-storey building.)

The key learning from this, for IDS in practice, is that experienced IDS practitioners need to develop and implement staged training/emersion for less experienced colleagues, over a period of time, to enable them to develop the knowledge and skills to successfully engage in integrated design. For universities, the key learning is that IDS would be better implemented much earlier in the respective architecture / engineering / construction management degrees, allowing emerging designers to develop and apply skills gradually.

Nevertheless, despite these limitations, a range of passive and active energy solutions were proposed. Some of these are explained in more detail in the following section. A few examples are shown below, demonstrating the multi-faceted approach used by the designers (trying to consider, within the overall ‘mixed-use building typology’, the client’s brief, occupant health and comfort, and energy from the perspective of embodied and operational energy).

Angus Smith’s design (Figure 3-1) incorporates NCC classes 2, 6 and 9c. From an energy perspective it addresses the embodied carbon footprint of the building (materials selection and construction simplicity), control of solar radiation (orientation, shading, insulation, location of thermal mass), HVAC (hybrid natural and mechanical system), and renewable energy (335kW PV estimated to meet 88% of building electrical load).

Figure 3-1 "Meridian" - Designer Angus Smith

Tala Clewe's mixed-use design (Figure 3-2) addresses embodied energy (precast concrete for thermal mass, minimal waste and faster construction time); passive solar design principles (orientation, cross ventilation, shading), heat gain control (low-e glazing, green façade) and renewable energy (rooftop and carpark canopies).

Figure 3-2 "Fernhill Village" - Designer Tala Clewes

Wing Yee Leung's design (Figure 3-3) seeks to address climate change and resource scarcity. The energy focus is on flexible management of cooling demand (e.g. materials selection, orientation, shading, cross ventilation, solar chimney, biophilia) and optimisation of renewable energy.

Figure 3-3 Northern elevation - Designer Wing Yee Wiener Leung

3.2 Feasibility assessment of selected design solutions

This section examines some of the design solutions in more detail, providing some qualification and quantification of the feasibility of these solutions for this (and other) building typologies in this climate zone. These evaluations attempt to identify the extent to which the proposed solutions can assist in moving towards net zero carbon targets.

3.2.1 Vertical Green Systems (Zia Sabdia)

This analysis investigates the benefits of Vertical Greening Systems (VGS) from both an energy and a health/well-being perspective, particularly for the elderly. This is consistent with principle 15 of Factor 10 Design Principles[3]: to wring multiple benefits from single expenditures.

3.2.1.1 Types of VGS

Vertical Greening Systems include green facades (direct and indirect) and living walls (continuous and modular), with various sub-classifications as shown in Figure 3-4.

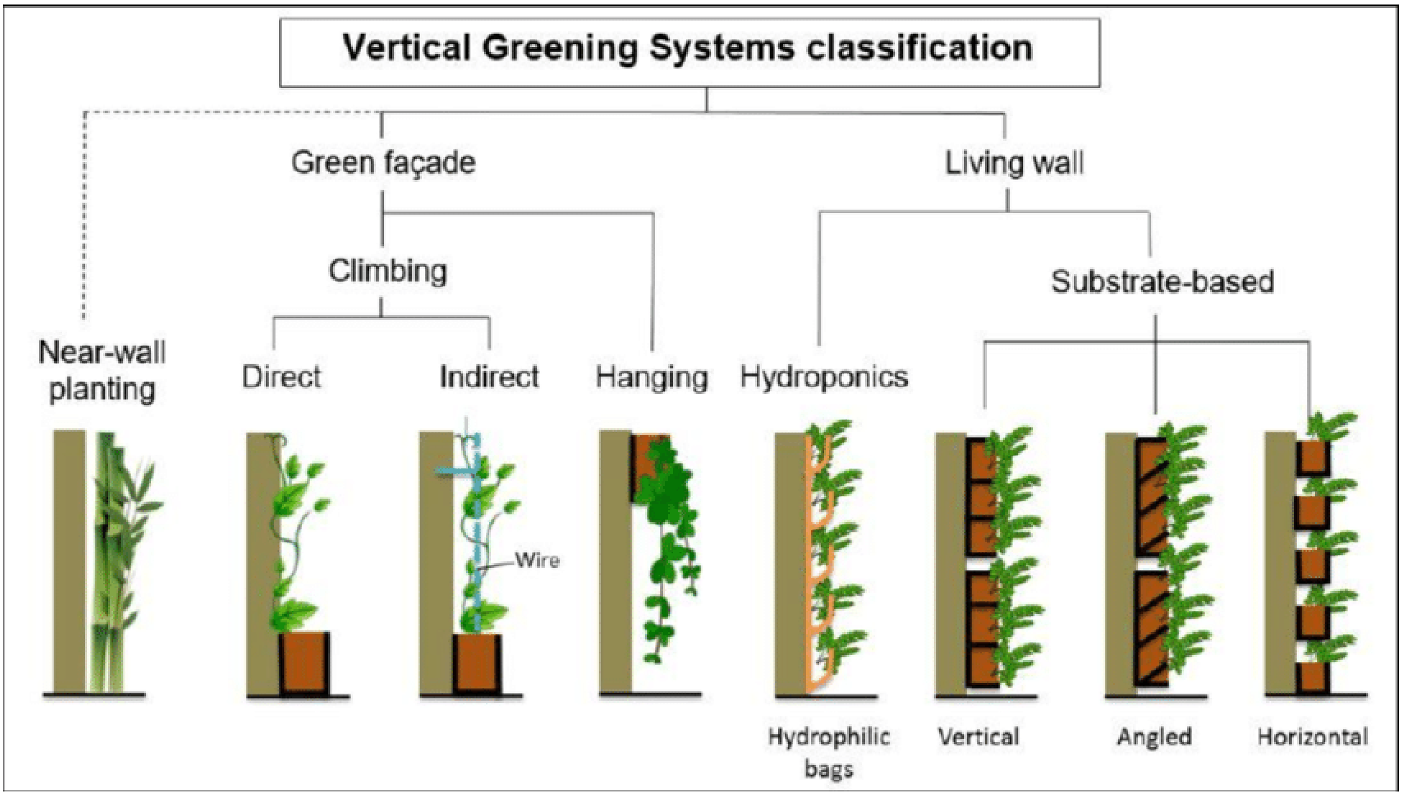

Figure 3-4 Types of vertical greening systems[4]

3.2.1.2 Thermal benefits of VGS

Indicative thermal benefits of VGS are shown in Table 3-2, showing their impact on internal and external temperatures, and on reducing heat transfer through the building envelope. Both would impact on the space cooling load of a building in the subtropics, reducing the energy required for space cooling. The study by

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[3] Factor 10 Engineering Design Principles evolved out of the work of the Rocky Mountain Institute. They are based on whole-system thinking and integrative design to produce radical energy efficiency. These Engineering Design Principals are discussed in more detail in Section 4, in particular showing their correlation with the Integrated Design process for net zero carbon.

[4] Al-din, SSM., Iranfar, M. 2019. The validity of beauty in the functionality of the vertical greenery systems (VGS) in interior surfaces of buildings. *International Conference of Contemporary Affairs on Architecture and Urbanism*. Turkey.

Coma et al. (2017) compared the use of a direct green façade and a continuous living wall against a bare wall in a subtropical climate, to determine the potential energy benefits. The study found that the average energy savings for the direct green facade during the cooling period and heating period was 19.72% and 0.77% respectively. For the continuous living wall the average energy savings during cooling and heating period were 44.34% and 3.58% respectively. This indicates that VGS provides more thermal benefits in summer compared to winter, and the continuous living wall provides more than double the potential energy benefits of the direct green facade. Green facades, however, are likely to have lower construction and maintenance costs (and hence shorter payback periods) compared to living walls (Perini and Rosasco, 2013), although this will depend on the local cost of energy (kWh and kW), and the technology readiness level and market penetration of specific technologies in the local area at any one point in time.

Table 3-2 Thermal benefits of VGS (selection)

Category of green infrastructure	Type of green infrastructure	Findings	Source
Green Facades	Direct	Reduce external wall temperature by 12.8°C. Reduces thermal lag through the wall	Perini, K., & Rosasco, P. (2013). Cost-benefit analysis for green façades and living wall systems. *Building and Environment 70*, 110-121. Coma, J., Perez, G., Gracia, A. d., Bures, S., & Urrestarazu, M. (2017). Vertical greenery systems for energy savings in buildings. *Building and Environment 111*, 228-237.
Living Walls	Continuous	Reduces external wall temperature by 19.5°C. Reduces thermal lag through the wall.	Coma, J., Perez, G., Gracia, A. d., Bures, S., & Urrestarazu, M. (2017). Vertical greenery systems for energy savings in buildings. *Building and Environment 111*, 228-237.
Green Facades	Indirect	Reduces internal and external wall temperature. Reduces internal and external air temperature by 3.6°C and 2.7°C respectively.	Zhang, L., Deng, Z., Liang, L., Meng, Q., Wang, J., & Santamouris, M. (2019). Thermal behavior of a vertical green facade and its impact on the indoor and outdoor thermal environment. *Energy & Buildings 204*, 1-14.
External Gardens	N/A	Reduces surrounding air temperature by 1.66°C and reduces Urban Heat Island (UHI) effect.	Mitterboeck, M., & Korjenic, A. (2017). Analysis for improving the passive cooling of building's surroundings through the creation of green spaces in the urban built-up area. *Energy and Buildings 148*, 166-181.

3.2.1.3 General benefits of VGS

Much literature reports on benefits of various VGS systems. An indicative selection of these benefits is shown in Table 3-3.

Table 3-3 General benefits of VGS

Type of Benefit	Specific benefit	Source
Acoustics	Noise reduction 2-8dB reported	Perini, K., & Rosasco, P. (2013). Cost-benefit analysis for green façades and living wall systems. *Building and Environment 70*, 110-121
Air quality	Reduction in NO2 and PM10 by 15% and 23% respectively (but need to avoid plants with toxins etc)	Pugh, T. A., Mackenzie, A. R., Whyatt, J. D., & Hewitt, C. N. (2012). Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons. *Environmental Science and Technology*, 7692-7699
Visual appeal	Enjoyable, admirable and ecological beauty	Sutton, R. (2014). Aesthetic for Green Roofs and Green Walls. *Living Architecture*.
Social	Adds aesthetic value and building identity Promote movement around and within the building	Hui, S. (2013). Thermal regulation performance of green living walls in buildings. *Innovation and Technology for Built Environment* Dahlkvist, E., & Engstrom, M. (2020, September 30). Residents' use and perceptions of residential care facility gardens. *Older People Nursing*, 1-10
Educational	Raise awareness of importance of ecology; physical teaching resource for biology, art, sustainability	Dahlkvist, E., & Engstrom, M. (2020, September 30). Residents' use and perceptions of residential care facility gardens. *Older People Nursing*, 1-10 Hop, M., & Hiemstra, J. (2012). Contribution of green roofs and walls to ecosystem services of urban green. *Acta Horticulturae*.
Health	Increases socialisation, relaxation, simulation of senses and memories of the past	Dahlkvist, E., & Engstrom, M. (2020, September 30). Residents' use and perceptions of residential care facility gardens. *Older People Nursing*, 1-10
	Increases mean quality of life, reduces depression and agitation	Edwards, C. A., McDonnell, C., & Merl, H. (2012). An evaluation of a therapeutic garden's influence on the quality of life of aged care residents with dementia. *Dementia 12*, 494-510
	Decreases stress, improves patient recovery rate, increases resistance to illness	Sheweka, S., & Magdy, N. (2011). The Living walls as an Approach for a Healthy Urban Environment. *Energy Procedia*, 592-599.
Biodiversity	Increases wildlife and total species (birds, insects)	Mayrand, F., Clergeau, P., & Vergnes, A. (2018). Vertical Greening Systems as Habitat for Biodiversity. *Nature Based Strategies for Urban and Building Sustainability*, 227-237.
Waste water	Future potential to integrate with grey water or blackwater systems	Pradhan, S., Al-Ghamdi, S. G., & Mackey, H. R. (2019). Greywater treatment by ornamental plants and media for an integrated green wall system. *Internaltional Biodeterioration and Biodegration*. Jin, Z., Xie, X., Zhou, J., Bei, K., Zhang, Y., Huang, X., & Zhao, M. (2018). Blackwater teatment using vertical greening. *Bioresource Technology*, 175-181.

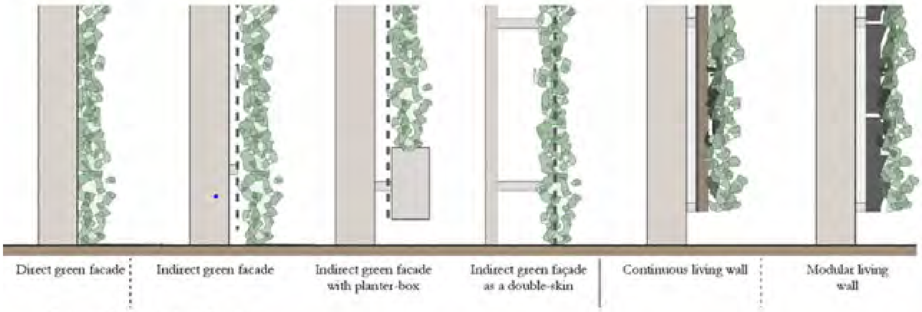
One of the client's key design principles for this IDS was to consider the needs of elderly residents, in particular elderly people with dementia. The benefits of VGS outlined above, have been mapped to the ten Design for Dementia Principles (Table 3-4), further highlighting the multiple benefits that can be captured from these technologies (thermal, energy, general, and dementia).

Table 3-4 VGS links to Design for Dementia

Dementia Friendly Design Principle	Satisfied (Yes/No)	Active / Passive	Specific benefit
Unobtrusively reduce risks	Yes	Active	Visual, Health
Provide a human scale	No	-	-
Allow people to see and be seen	No	-	-
Reduce unhelpful stimulation	Yes	Active	Thermal, Acoustic, Air Quality
Optimise helpful stimulation	Yes	Active	Visual
Support movement and engagement	Yes	Passive	Thermal, Social
Create a familiar space	Yes	Active	Visual
Provide opportunities to be alone or with others	Yes	Passive	Social
Provide links to the community	Yes	Active	Educational
Respond to a vision for way of life	Yes	Passive	Social, Biodiversity, Waste water

This evaluation informed Hung-Yi Kuo's design (Figure 3-5) that combines the multiple benefits of VGS with a 'solar chimney' that is used to enhance natural ventilation. The design also incorporates rooftop PV.

Application of Green Wall System



Types of Green Wall System

Figure 3-5 VGS system applied to mixed-use building - Designer Hung-Yi Kuo

3.2.2 Adaptable Design (Wing Yee Wiener Leung + Wendy Miller)

This design element takes into consideration whole-of-life aspects, by having movable walls to reduce the refurbishment costs of living apartments when demographics change. The idea is based on the work of Levitt Bernstein, who proposed this approach for an aged care facility in the UK. It is similar to the approach taken for retail and office buildings which are frequently designed with movable internal partition walls.

This 'adaptable building' concept was also demonstrated in multiple ways at the International Building Exhibition IBA Hamburg (2006 – 2013):

- Architects Fusi & Ammann designed "Case Study #1 Hamburg", responding to demand for apartments (and workplaces) that can respond quickly and easily to changes in family structure[5].
- A different approach combined smart planning and low-cost goals, appealing to the DIY market. It enabled residents to 'construct' the internal layout of their apartment according to their current needs and modify them as their needs changed[6].

The general idea is to create residential parts of mixed-use buildings, consisting of 'apartments' or 'flats' where most internal walls are not load bearing. Internal 'partition walls' can be moved, providing flexibility in layout planning. This is suitable for people of any age. Main service areas (e.g. kitchens and bathrooms) are located in 'building cores', similar to the core services of office buildings.

In this context (refer to Figure 3-6), it means that the residential component of a mixed-use building could be designed for different types of residents over time (e.g. from students to singles to couples to elderly). Whilst not affecting the operational energy of a building, this design flexibility has a significant benefit for mixed-use buildings in areas of demographic change.

For this particular location, the residential units could be used for student or general accommodation purposes in the first instance, morphing into supported or assisted living accommodation as the demand for such accommodation increases in the area over time (or vice versa). Building services (including HVAC as well as fire safety and access/egress) would need to be designed in the initial building to account for all possible future uses or be designed in such a way to enable relatively easy retrofit. The significant energy implication relates to Scope 3 emissions which are not yet fully considered (if at all) in net zero carbon goals set for buildings and building owners/operators.

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[5] https://www.internationale-bauausstellung-hamburg.de/en/projects/the-building-exhibition-within-the-building-exhibition/smart-price-houses/case-study-1/projekt/case-study-1.html

[6] https://www.internationale-bauausstellung-hamburg.de/en/projects/the-building-exhibition-within-the-building-exhibition/smart-price-houses/basic-building-and-do-it-yourself-builders/projekt/basic-building-and-do-it-yourself-builders.html

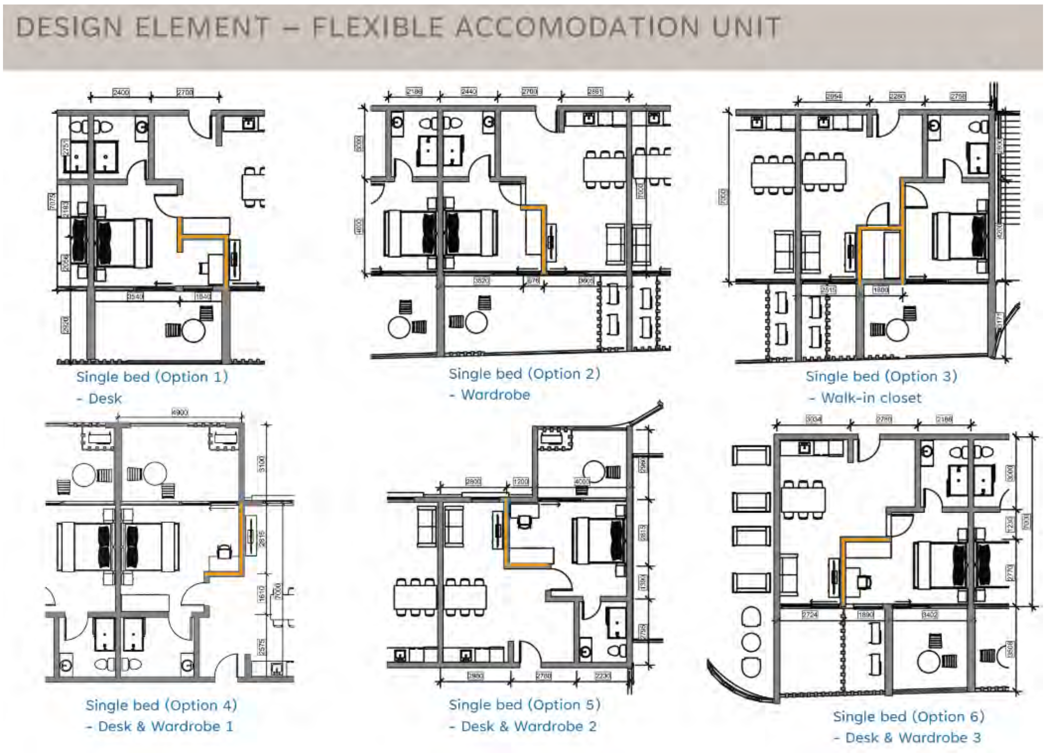

Figure 3-6 Flexible Accommodation Unit - Designer Wing Yee Wiener Leung

3.2.3 PV + Battery-Supercapacitor (BSC) hybrid storage (James Robertson, Aaron Liu)

A question for mixed-use buildings, in particular those incorporating residential uses, is:

> "*what is the ultimate renewable energy system design that incorporates aspects of renewable energy, backup power and energy storage?"*

This technology evaluation focuses on an 'early market' technology for energy storage, while addressing concurrent client goals of minimising environmental impact, increasing lifespan and lowering energy costs.

3.2.3.1 Baseline energy use

The building design for this analysis consists of 44 bedrooms (12 two-bedroom apartments and 20 one-bedrooms apartments) and 3180m^2 of general retail and office space (Figure 3-7). Daily energy use for each of the mixed-uses is calculated as:

- Residential: 32 beds * EUI of 20kWh/bed/day (includes back of house / common building services)[7]
- Office tenancies: 1590m2 * 76kWh[8]
- Retail tenancies: 1590m2 * 203kWh[9]

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[7] Liu, A., Miller, W., Chiou, J., Zedan, S. 2021. Aged Care Energy Use and Peak Demand Change in the COVID-10 ear: Empirical Evidence from Australia. Buildings, Volume 11, Issue 12. https://doi.org/10.3390/buildings11120570

[8] EUI for office tenancies from NABERS FY2020 ratings (excluding outliers), as reported in *Determining office tenancies energy end use*. Final Report June 2021. Energy Efficiency Council. www.eec.org.au

[9] EUI assumed to be 20% better than the average energy intensity of retail tenancies (2012) as reported in *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia. Part 1 – Report*. November 2012. Council of Australian Governments (COAG) National Strategy on Energy Efficiency

Figure 3-7 Render of proposed mixed-use building - Designer Angus Smith

3.2.3.2 About PowerCap energy storage system

Sustainable Energy Equities Pty Ltd, trading as Zero Emissions Development (ZED), is a Queensland company that offers a commercially available energy storage system called PowerCap. According to the manufacturer, PowerCap is a "metal-oxide graphitic pseudo-capacitor battery"[10]. Battery-Supercapacitor (BSC) hybrid devices consist of a high-capacity battery-type electrode and a high-rate capacitive electrode. Supercapacitors are reported in scientific literature to be able to respond to high frequency fluctuations, increasing the lifetime of the battery and decreasing the size requirement[11],[12]. PowerCap has a 10 year standard warranty plus an additional 10 year extendible warranty, compared to 'standard' battery system warranty of 10 years and charging cycle limits. As well as the integrated supercapacitor, PowerCap has an integrated inverter for DC to AC requirements. From an environmental perspective, this system utilises graphene capacitor technology made from sugar cane waste and is claimed to be fully recyclable at the end of its life. ZED is also developing a hydrogen battery tank which is expected to be a replacement for current diesel generators. The system parameters of the commercial PowerCap system analysed here are shown in

Table 3-5.

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[10] https://zed.energy

[11] Singh, P and Lather, JS (2021). Power management and control of a grid-independent DC microgrid with hybrid energy storage system. *Sustainable Energy Technologies and Assessments*, Vol 43.

[12] Ravada, B.R, Tummuru, N.R, Ande, B.N.L (2021) Photovoltaic-Wind and Hybrid Energy Storage integrated multi-source *IEEE Transactions on Sustainable Energy,* Vol 12, No2, PP. 83091

Table 3-5 Self-reported characteristics of PowerCap commercial energy storage[13]

Criteria	Details
Energy storage (per system)	50 kWh, scalable configuration
Storage mechanism	Hybrid electrostatic and electrochemical
Dimensions	520 x 702 x 1904 mm
Weight	602 kg
Energy density	Graphene 600-700Wh/kg compared to lithium-Ion ~ 180Wh/kg
Charge / Discharge	<99% depth of discharge (DC basis) Configurable for 1-4 hour continuous charge / discharge
Warranty and Service Life	Warranty 20 years; Service life 25-30 years
Voltage	Three phase 400V
Battery Management System	
Response time	200ms
Demand response capability	TÜV and SUD tested and certified SCADE communication with grid operators Can be deployed for utility-scale frequency stabilisation
Environmental credentials	100% recyclable Graphene biodegradable

3.2.3.3 PV system sizing, area and costs

The PV system required to meet the expected average daily demand of the building under study was calculated as follows.

PV system size required to meet daily energy use = EUI * no. of beds * peak sun hours * PV derating

EUI = 20kWh/bed/day;

No of beds = 32.

$$Design\ estimate\ for\ total\ energy\ use = residential\ energy\ needs + retail\ needs$$

$$= 20 \times 32 + 1590 * 203/365 = 1524 kWh/day$$

Please note that for this feasibility evaluation, the office energy needs have been considered in the residents' energy use intensity (EUI) since the office spaces are to support services delivered to the residents.

Peak sun hours (Brisbane) = 5.1kWh/m^2 [14]

PV derating (Brisbane) = 0.83 [15]

Answer (rounded up) = $\frac{1524}{5.1 \times 0.83} = \mathbf{360\ kWpeak}$

This is a ballpark estimate of PV system required to meet the site electricity demand to reach a net zero electricity goal.

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[13] https://powercap.com.au

[14] https://www.hotspotenergy.com/DC-air-conditioner/australia-solar-map.php

[15] Clean Energy Council https://www.solarchoice.net.au/blog/how-much-energy-will-my-solar-cells-produce/

Area required for that size PV system = $\frac{360}{0.3} \times 2 = \mathbf{2400\ m^2}$, assuming 300W panels are used; each 300W panel is $2m^2$. Please note additional spaces need to be allowed for installation, access to maintenances etc.

Approximate cost of the 360kWp system including panels, inverters, wiring and labour[16]

= $360 \times \$1200 = \$4{,}320{,}000$, assuming $1200 per 1kWp solar PV system

Considering

- 70% of the PV system electricity is used onsite and electricity cost is at $0.25 per kWh
- 30% of the PV output is exported to the grid with a feed-in tariff at $0.08 per kWh
- A year has 365 days

The 360kWpeak PV system is expected to have a 26% simple rate of return (Table 3-6) and likely to reach return on investment (positive cashflow) within 4 to 5 years from the base year.

Table 3-6 Return on investment study for the PV system

No.	Description	Calculation	Outcomes
1	PV system investment	$360 \times \$1200$	$432,000.00
2	Yearly self-use savings	$360 \times 5.1 \times 0.83 \times 70\% \times \$0.25 \times 365$	$97,337.84
3	Yearly feed-in tariff income	$360 \times 5.1 \times 0.83 \times 30\% \times \$0.08 \times 365$	$13,349.19
4	Yearly savings + income	Row 2 + Row 3	$110,687.02
5	Simple rate of return	Row 4 / Row 1 = $110,687/$4,320,000	**26%**

This financial analysis is based on a net zero electricity goal without the consideration of site battery energy storage. The estimated PV system is likely to be further engineered due to site constraints, cost optimisation and compliance with grid requirements. The following section evaluates a potential battery system's sizing, space requirements and cost impacts.

3.2.3.4 Battery system sizing, area and costs

A residential aged care facility has three different power services graded by the criticality of services provided:

- UPS (ICT equipment, life-preserving medical equipment, nurse call devices, patient monitoring systems)
- Essential services (general lighting, general power to patient areas; ventilation fans, fire safety services)
- Non-essential services (everything else)

Typically backup generators are used for all UPS and essential services, in the event of loss of mains power.

If a battery storage system is utilised to absorb any daytime excess and to be used for off-peak hours, that system will be charged during the day (via excess PV) and utilised over night or at peak times post PV generation). To estimate 30 minute peak electricity demand for the mixed-use building, the following data and assumptions are used:

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[16] Liu, A., Miller, W., Cholette, ME., Ledwich, G., Crompton, G. 2021. A Multi-dimension Clustering-based method for Renewable Energy Investment Planning. *Renewable Energy*, Vol 172, pp651-666. https://doi.org/10.1016/j.renene.2021.03.056

- The site's estimated daily electricity use is 1524kWh.
- The average power demand is 1524/24hours = 63.5kW.
- If peak demand is 5 times the average power demand, the peak demand = 63.5*5=318kW.
- The building's peak electricity demands are more likely to occur between 11am and 4pm.

If 25% of the daily energy use is generated with PV, stored with batteries and utilised outside of solar hours, the site would need **8 units of 50kWh battery energy storage systems** (1524kWh*25%=381kWh, 381kWh/50kWh=7.62).

Each of the 50kWh battery system storage system has a footprint of 0.52X0.702m. 8 of the units would need an area of 5.1m length by 4.9m width (Figure 3-8), considering

- a layout of 2 rows and 4 units in each row
- a minimum of 1.5 m distance in front of each unit
- a minimum of 1 m distance on the back of each unit to a building wall
- a minimum of 1.5 m distance from either side of each row to a building wall

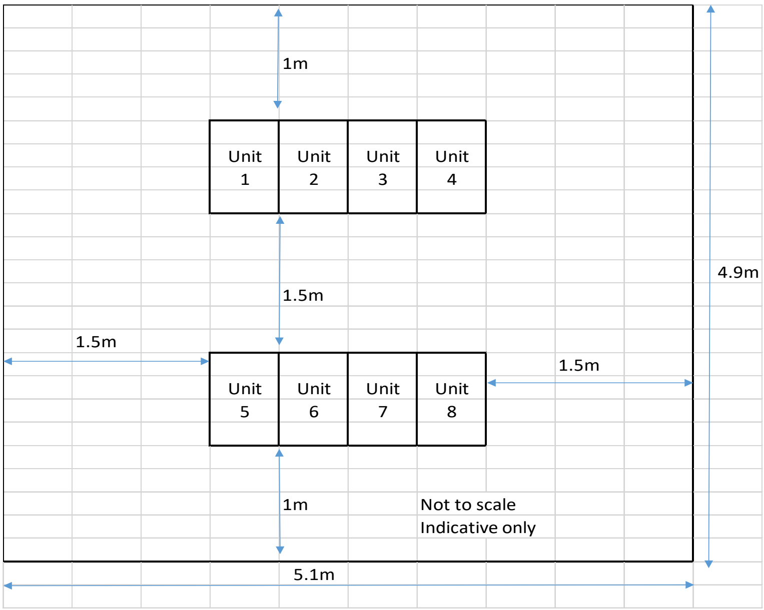

Figure 3-8 Indicative layout diagram for the battery systems

Assuming the battery energy storage system is at $1000 per kWh rating, the system yearly energy bill saving due to self-use is $34,766, using $0.25/kWh electricity price (Table 3-7). More streams of income may be possible when virtual power plants or wholesale demand response mechanism are considered.

Table 3-7 Return on investment study for the battery energy storage system

No.	Description	Calculation	Outcomes
1	Battery system investment	$8 \times 50 \times \$1000$	$400,000.00
2	Yearly self-use savings	$381 \times \$0.25 \times 365$	$34,766.25
3	Simple rate of return	Row 2 / Row 1 = $34,766/$400,000	**8.69%**

3.2.3.5 Questions to consider in design

One of the ‘errors’ observed in this energy system solution proposed (by the early career engineer) related to a misunderstanding of the difference between product warranty life and typical useful life. Any design evaluations need to clearly articulate which of these the calculations are based on. Refer to Table 3-8 for these differences, as applied to PV panels, inverters, battery storage systems etc.

Table 3-8 Energy system components, warranty, and useful life

Component	Typical warranty	Typical useful life
PV panels	10 year panel warranty and efficiency warranty over 20-25 ears	25-30 years or more depending on technology and environment
Solar inverter	5 years	5-12 years depending on technology and installation environment
Battery storage (lithium ion)	5-10 years (5,000 – 10,000 cycles)	15 years
BSC storage system	10 + 10 years (20,000 cycles)	
Diesel generator	1-2 years	15,000 – 50,000 hours or more, depending on technology, operation and maintenance

Additional questions that need to be addressed in the design of energy storage systems as part of a renewable energy solution include:

- ☐ Does the Distribution Network Service Provider (DNSP) allow for parallel export (from either the PV or the generator or the energy storage system)?
- ☐ What % of daily energy use and peak demand is the system expected to cover?
- ☐ How could a combination of a BSC storage system and backup generator be used to manage peak demand and limit solar exports (maximise solar self-utilisation)?
- ☐ What metering and control systems (e.g. BMS, EMS) are needed to enable the above, as well as enable possible future participation in energy market mechanisms?

These questions were not addressed in this evaluation.

> “Set aside all conventional methods and assumptions and jump to a completely new design space with no preconceptions.” 10Xe Principle #10

3.2.4 Value of parametric evaluation (Andrew Williams, Amir Tabadkani)

As noted previously in section 3.1, many of the architectural designs did not provide substantial evidence of a knowledge of building science, in particular the properties of materials, and how the selection of materials influences internal heat gains and hence the cooling required to be met by a HVAC system (which then impacts on peak demand as well as the renewable energy required to meet net zero energy targets). This section demonstrates the capability of parametric design to inform material selections that impact on the energy performance goals of a mixed-use building.

3.2.4.1 The IDS scenario

The analysis is based on a design by emerging architect Xiaomeng (Tibby) Tian, as shown in Figure 3-9.

Figure 3-9 Fernhill Multigenerational Community Hub - Designer Tibby Tian[17]

3.2.4.2 About parametric design

Emergence of object-based parametric design as an underlying logic of new design developments is changing the nature of design practices in the sustainable construction industry. Parametric design facilitates the use of parameters and their correlations in defining a design, whether as a geometrical form or its environmental performance. The procedure of parametric design includes the following major elements:

- The parameters that define the design variations as INPUTS
- A generative mechanism that defines the rules and algorithms behind the functions
- The design targets as OUTPUTS
- The optimum design selection.

Each iteration begins with defined inputs to establish the initial parameters, which, next, are translated into the design output through the algorithmic functions. This feature enables co-designers a flexible interface to discover a wide range of variants and design alternatives against building code baselines such as NCC19 DtS solution which could be demonstrated through Parallel Coordinate Plots (PCP), as shown in Figure 3-10. In this example, reading from left to right, four parameters are modelled, calculating the cooling, heating and energy impacts, then the optimum design for two specific locations.

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[17] Tibby's design sought to maximise natural ventilation, reduce solar heat gain through sun control and careful orientation of glazing; incorporate green facades for energy and well-being benefits, and optimise solar energy harvesting from the roof and solar awnings.

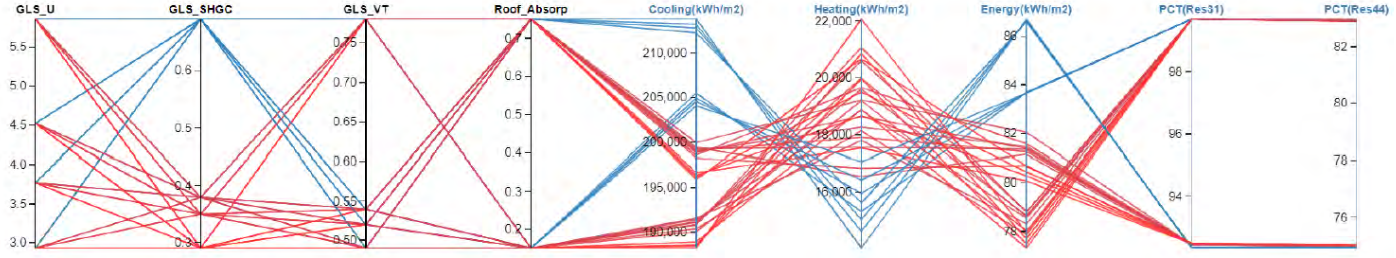


Figure 3-10 Example of a parallel coordinate plot

3.2.4.3 Parametric environmental assessment for this IDS scenario

Tibby's design was modelled through a parametric and algorithmic-based interface called Grasshopper which is a plugin for Rhinoceros 3D modelling software. Grasshopper itself embeds a wide range of plugins for different applications including building environmental performance through open-source tools, namely Ladybug-Tools.

Ladybug-tools converts the architectural geometrical models into thermal zones through validated simulation engines including EnergyPlus and OpenStudio for building energy performance evaluations. Figure 3-11 illustrates the energy / thermal comfort simulation process in three simple steps from geometry to conditioned/unconditioned thermal zones.

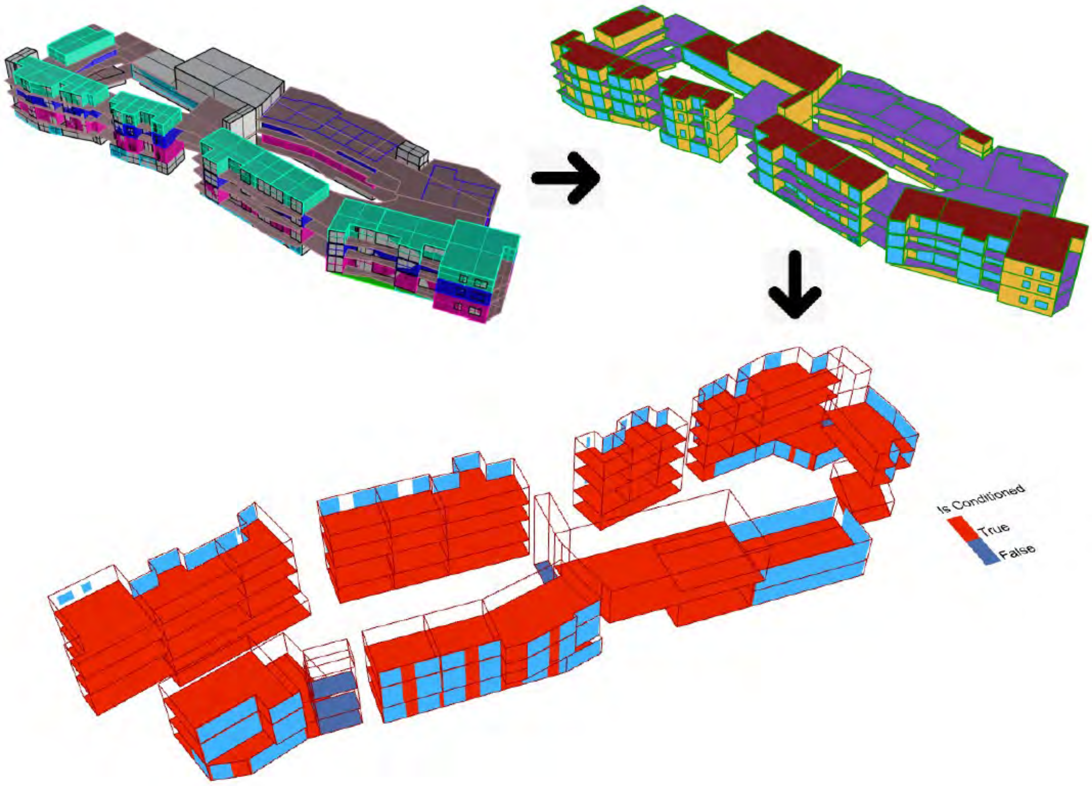


Figure 3-11 Simulation workflow for Tibby's design

Two scenarios are considered for further parametric design optimization:

- Air-conditioned building where the thermal zones are controlled with temperature setpoints to activate the HVAC system for cooling / heating when the indoor temperature exceeds the thermal comfort range of 21 to 24 C degrees
- Naturally-ventilated building where the windows of the residential spaces are automated based on indoor temperature to permit natural ventilation across the spaces and cool them down passively. However, two different window operations are set to evaluate the criteria:
    - Windows are operated based on indoor/outdoor temperature throughout the year:
        - Open the windows when the indoor temperature is above 21°C degrees (NCC2019)
        - Close the windows when the indoor temperature exceeds 24°C degrees (NCC2019)
        - If indoor temperature is within 21 and 24°C degrees, but outdoor temperature exceeds 25°C degrees, close the windows (NOTE: this is for illustrative purposes and does not intend to imply a recommended control strategy.)
    - Night ventilation was utilised, with the windows scheduled to be semi-open from 5pm to 6am daily (through all months) regardless of the outdoor temperature. (NOTE: this is for illustrative purposes and does not intend to imply a recommended night-time ventilation strategy.)

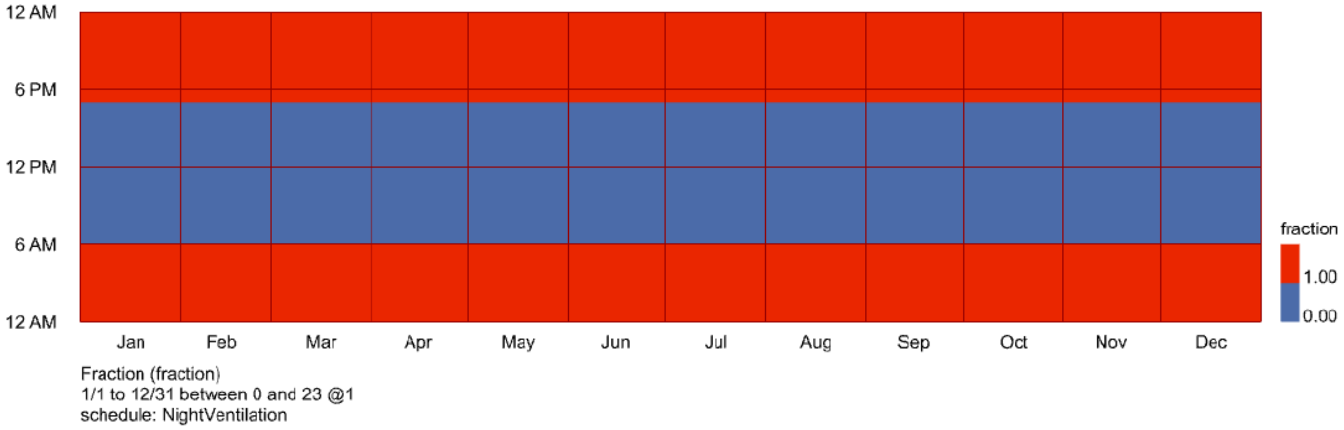


Figure 3-12 Night Ventilation Schedule (1= open; 2 = closed)

3.2.4.4 Parametric optimisation

To run the parametric optimization, a set of design variables are defined as inputs while energy consumption and thermal comfort are set as design targets or outputs. Table 3-9 shows the fixed and variable design parameters studied in this instance, which includes a total number 384 design alternatives for both scenarios. What this looks like, when scripted in Grasshopper, is shown in Figure 3-13.

Table 3-9 Design variables and targets

Parameters	Values
FIXED	
Roof R value	3.7
External Walls R value	2.0
HVAC System (for air-conditioned scenario)	Fan coil chiller with baseboard electric
Window operable percentage (for naturally-ventilated scenario)	50%
VARIABLE	
Roof solar absorptance	15% - 75%
Glass U value	*U*5.85 - *U*4.52 – *U*3.77 – *U*2.93
Glass Solar Heat Gain Coefficient (SHGC)	0.69 – 0.38 - 0.35 – 0.29
Glass Visual Transmittance (VT)	0.78 – 0.54 –0.52 – 0.49
Natural ventilation control type (for naturally-ventilated scenario)	Temperature controlled – night ventilation
TARGETS	
Air-conditioned scenario	Cooling – Heating – PMV/PPD thermal comfort
Naturally-ventilated scenario	Hours of ‘uncomfortable’ indoor temperature per year (i.e. hours below 21°C and above 24°C (NOTE: this is for illustrative purposes and does not intend to imply that ‘comfort’ is, or should be, restricted to 21-24°C)

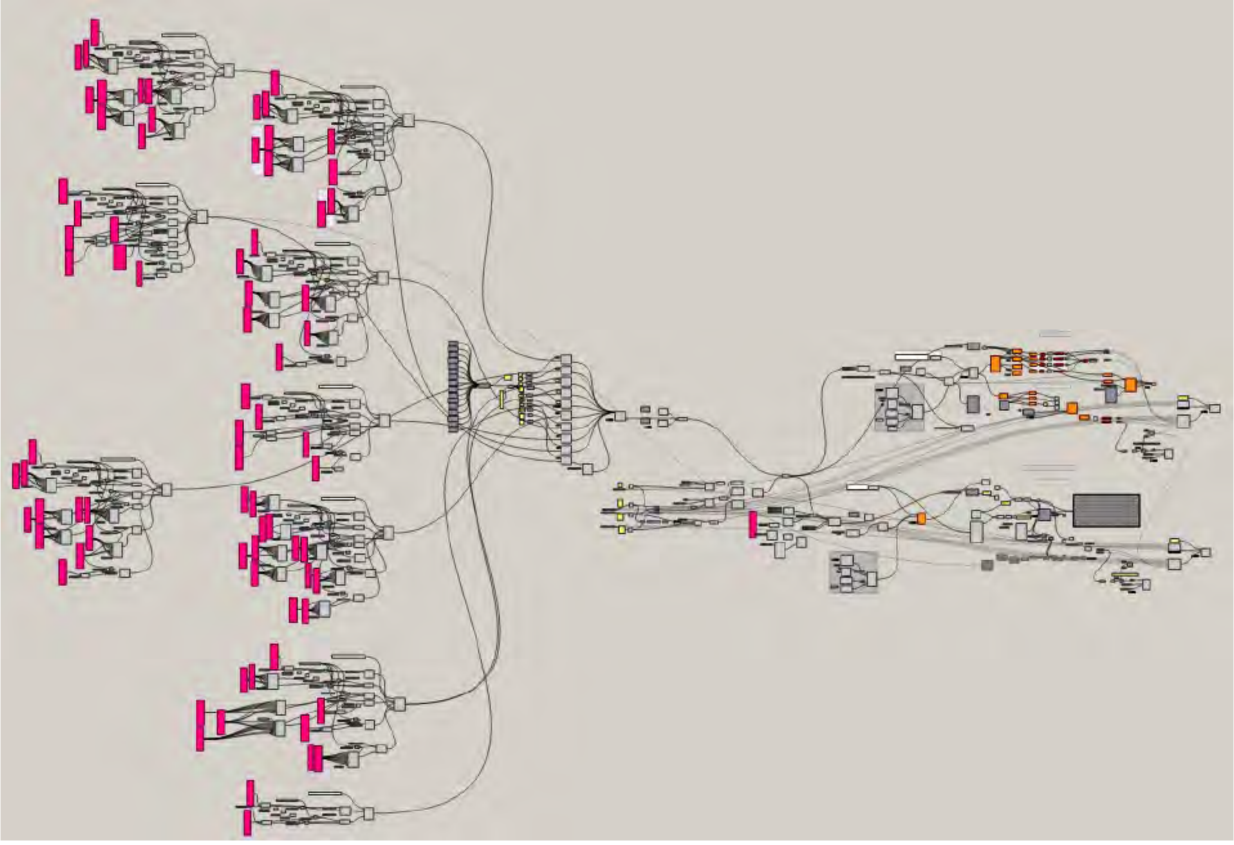


Figure 3-13 Parametric model scripted in Grasshopper interface

3.2.4.5 Results

To analyse the impact of each design option on both energy consumption and thermal comfort, a web-based tool called Design Explorer is used to illustrate the charts which allows the designer and client to play with different variables and estimate their implication on the targets. However, in this instance, two of the residential units on the North (Res 31) and South (Res 44) sides are selected to study the indoor thermal comfort across the year Figure 3-14.

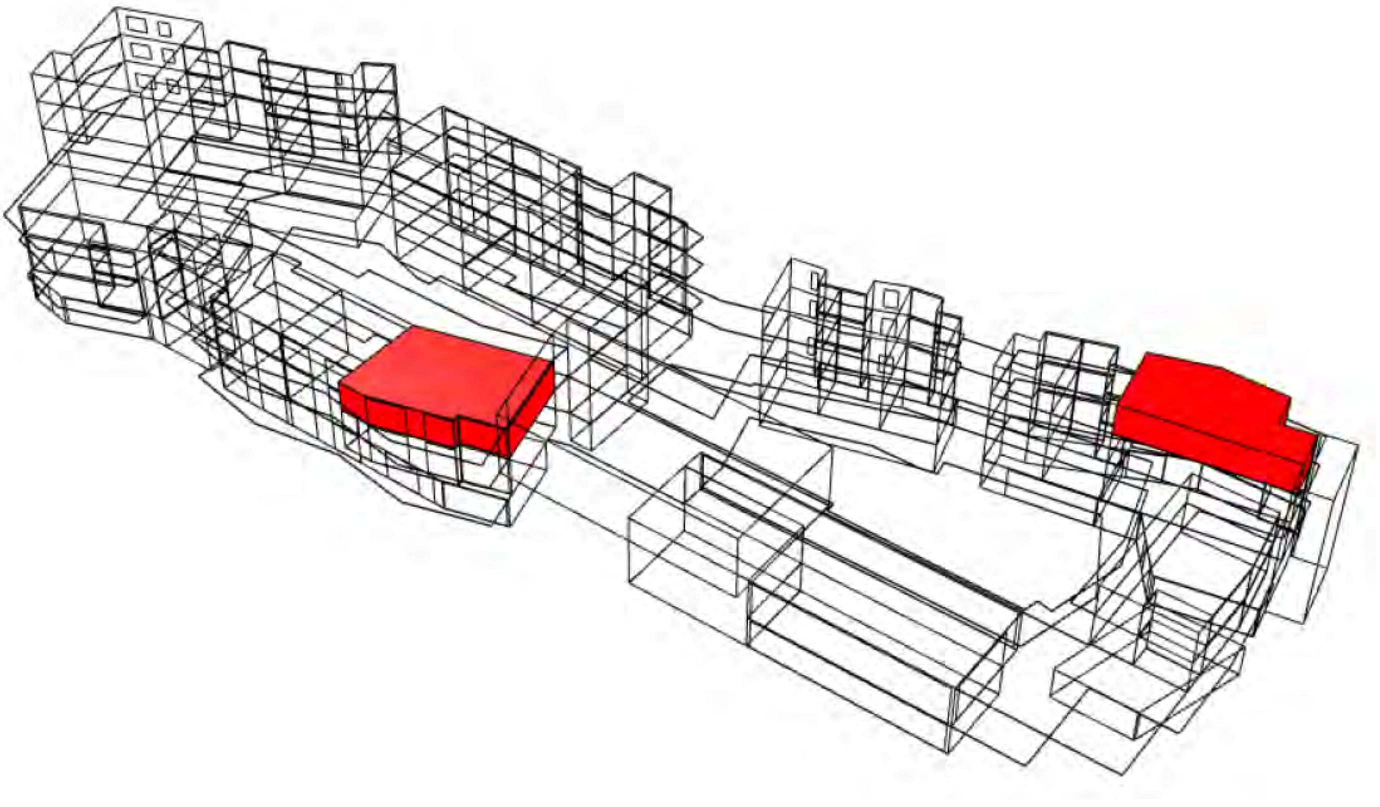


Figure 3-14 Selected residential units for thermal comfort analysis

3.2.4.5.1 Air-conditioned Scenario

Cooling energy demand is the main contributor to the building heating and cooling energy consumption (refer to Figure 3-15, columns 5 and 6) and the overall energy consumption (heating, cooling, fan and pump electricity) ranges from 77.5 to 87 kWh/m^2 (refer to column 7).

The minimum building energy consumption refers to the design options where the roof solar absorptance and glass SHGC play the most significant role to control the solar gains and consequently reduce the cooling loads. It is suggested to have the roof finishing material with a 15% solar absorptance (85% reflectance), while the glass SHGC should be within 29% and 35%.

If PMV/PPD thermal comfort is the key target, the results (Figure 3-16) are in line with the minimum energy required for the building, since decreasing the solar gain through the roof and glass could significantly improve the number of hours that are in the specified temperature range.

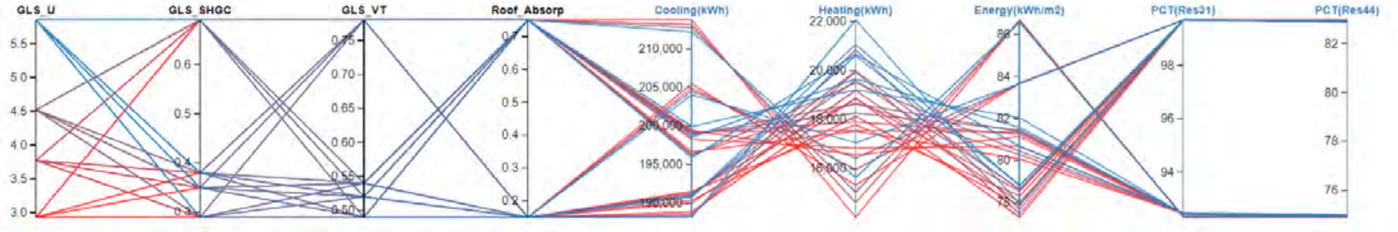


Figure 3-15 Energy requirements for the airconditioned scenario

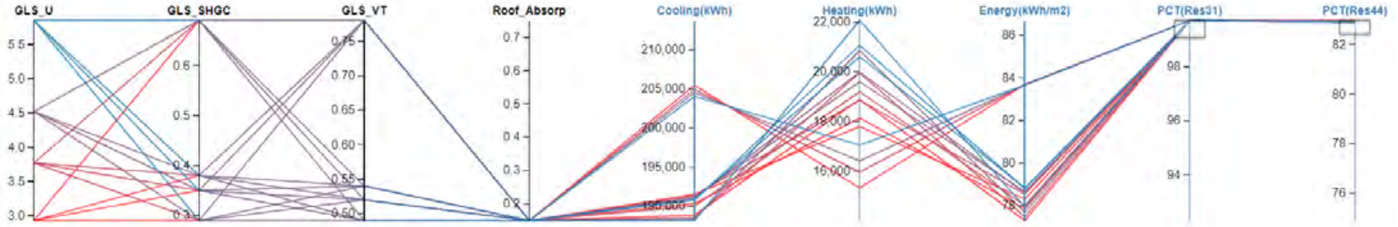


Figure 3-16 PMV/PDD results for airconditioned scenario

3.2.4.5.2 Naturally-ventilated Scenario

Applying natural ventilation as a passive strategy, without utilising HVAC systems, resulted in significantly less comfortable hours (defined in this simulation as 21-24°C) during the year, in which the maximum comfortable hours for both of the selected residential units was 19% of annual hours (Figure 3-17). This assumes daytime window opening/closing in relation to the indoor/outdoor temperature and night-time ventilation according to the schedule.

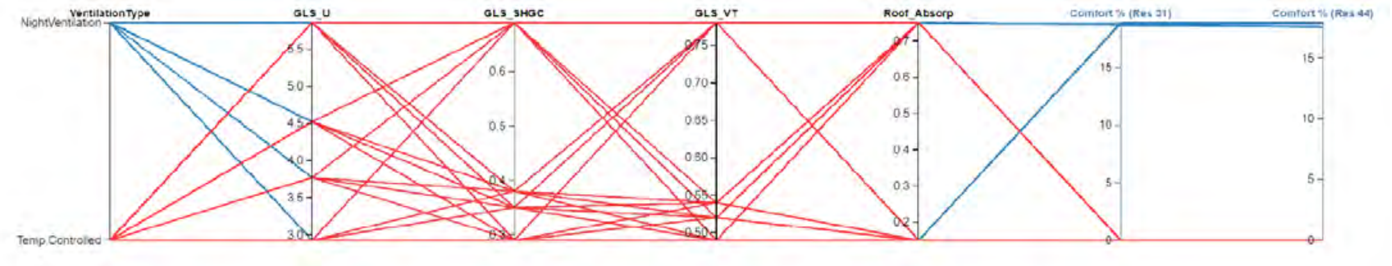


Figure 3-17 Natural ventilation % of annual hours within 21-24ºC for selected residential units

For the case of controlling ventilation by opening and closing windows based on indoor/outdoor temperature conditions, the selected residential units could not achieve any hours within the designated temperature range (21-24ºC) (Figure 3-18). Through this option, the indoor temperature varies from 33 to 47°C across the year. The existing excessive indoor temperature up to 45°C is because the windows are closed when the indoor temperature exceeds 24°C which then results in maintaining heat inside the space while having solar gain across the day. Therefore, this finding suggests closing the windows based on a maximum indoor temperature (24°C in this instance) is ineffective in contributing to occupant comfort especially for a climate like Brisbane (unless steps are taken to eliminate or reduce solar heat gain).

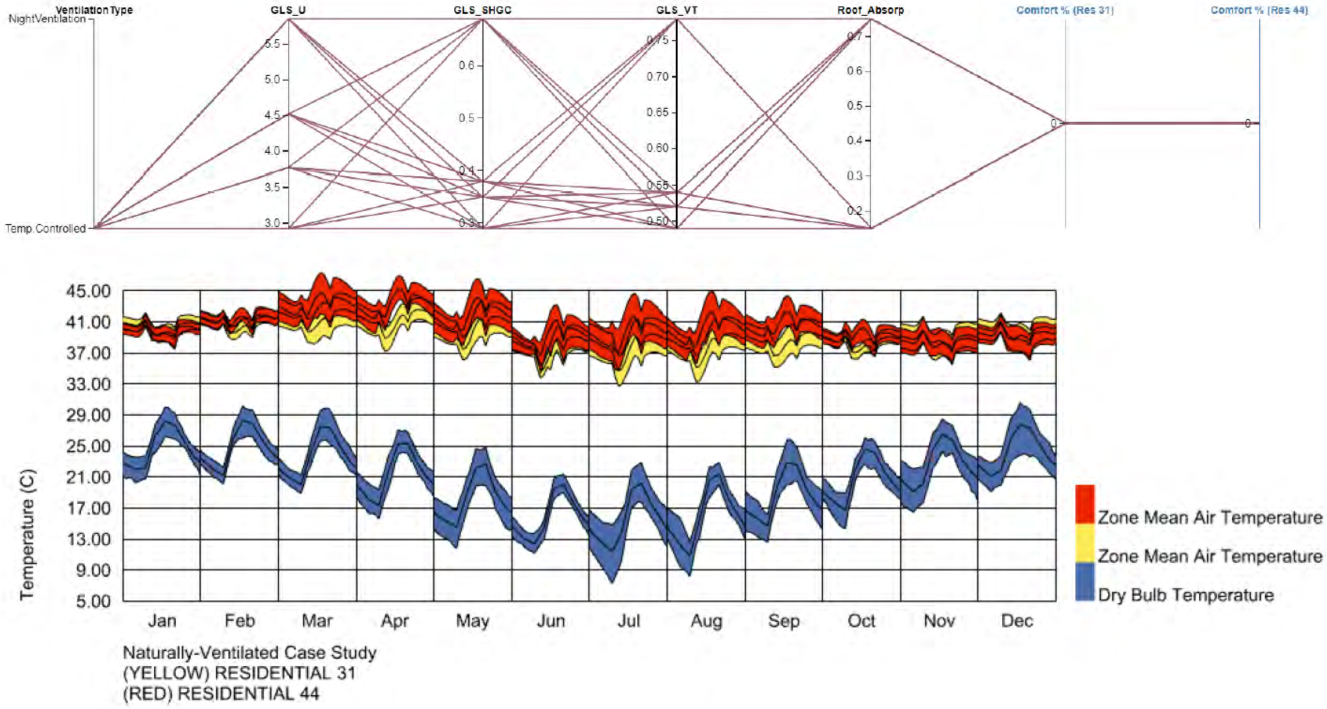
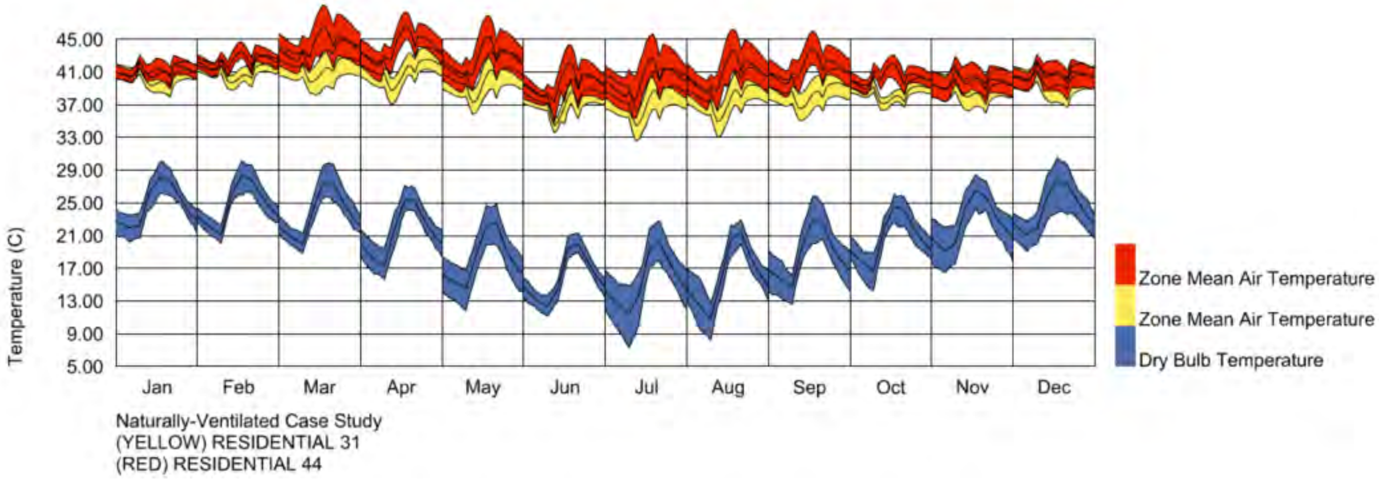


Figure 3-18 Natural ventilation performance for selected units

Alternatively, to illustrate the impact of a temperature-based window control scenario, the indoor maximum temperature condition to close the windows was removed for a single simulation design option and compared against the same design option including the maximum indoor temperature condition (Figure 3-19) (the minimum indoor temperature and maximum outdoor temperature remained unchanged in both cases). The comparison indicates a significant difference in improving the indoor thermal comfort by 32.6% and decreasing the indoor operative temperature within 17-37ºC throughout the year.



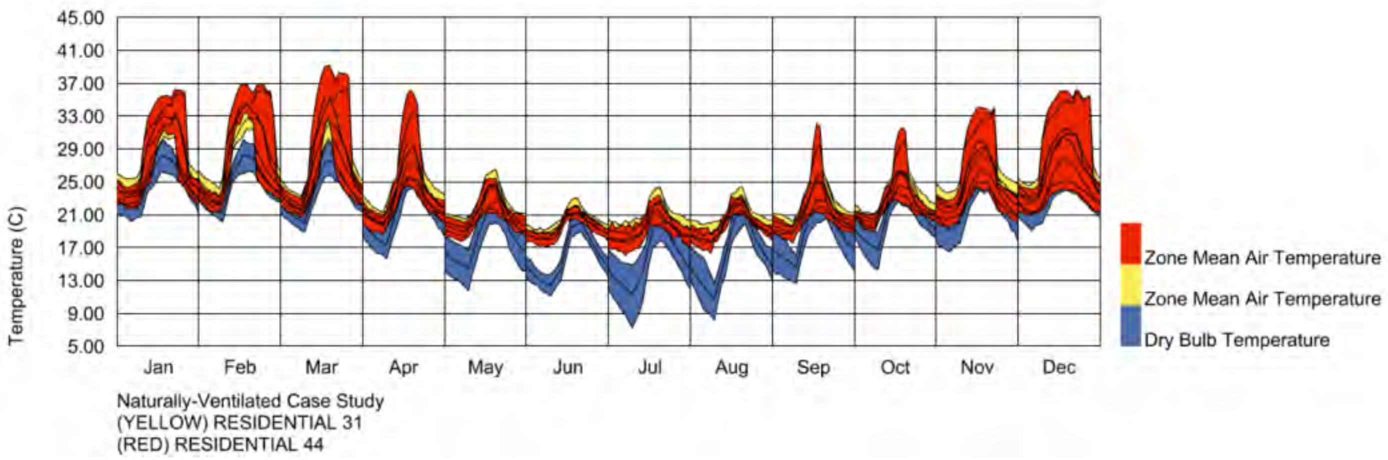


Figure 3-19 Example of temperature-based control impact on thermal comfort

If night time ventilation conditions are used for the window operation, there is a significant improvement of 'comfort conditions' for both residential units throughout the year. From the alternatives tested, reducing roof solar absorptance had the biggest impact on improving comfort (Figure 3-20 and Figure 3-21). Note that the optimum solutions could not provide any more comfort hours than the air-conditioned scenario (about 19%).

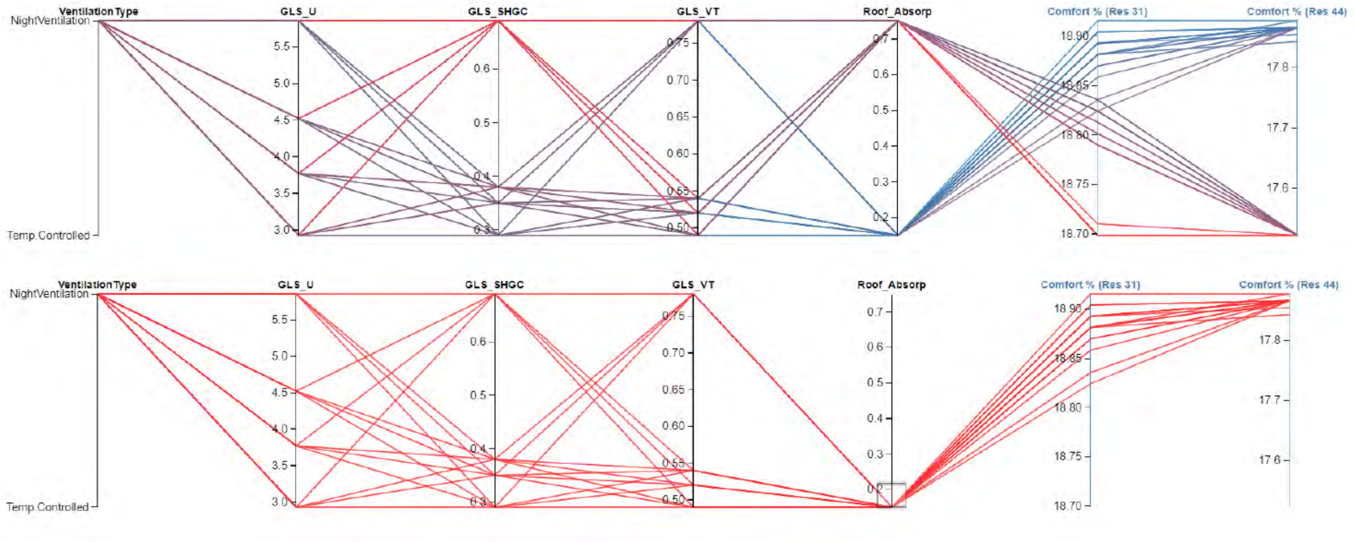


Figure 3-20 Night time ventilation impact on percentage of annual hours within 21-24oC

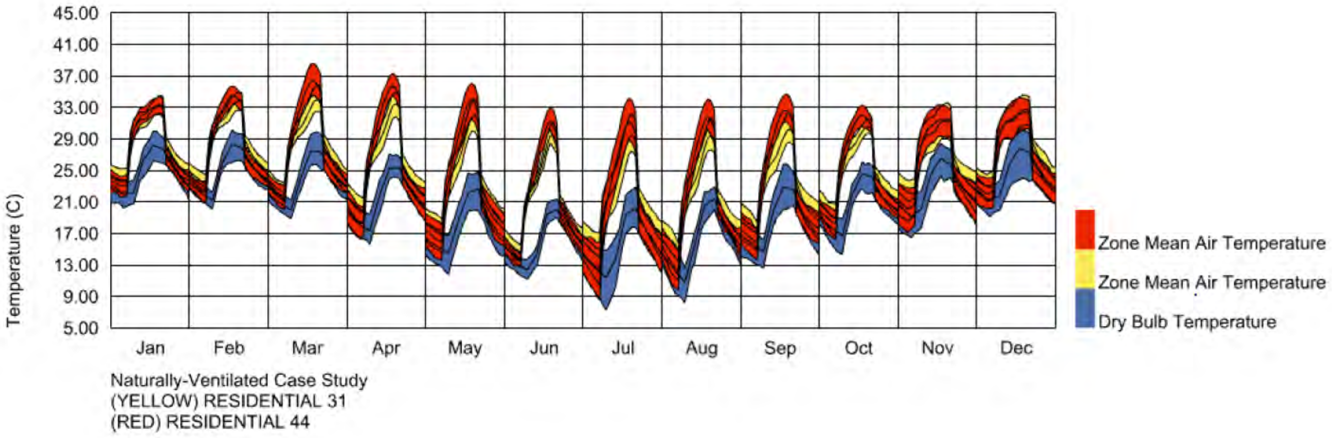


Figure 3-21 Example of temperature impacts of night-time ventilation

Comparing the two temperature-based window control with night-time natural ventilation scenario based on dividing the indoor temperature range into five ranges from below 18°C till above 28°C, it is evident that:

- The original temperature-based control scenario (including the maximum indoor temperature condition) always dictates an indoor temperature above 28°C (Figure 3-22, TOP) while in the revised one (excluding the maximum indoor temperature condition), almost 2700 hours of the year fall below 18C across the year (Figure 3-22, MIDDLE).
- The night-time ventilation resulted in distributing the indoor temperature from 18°C up to above 28°C (Figure 3-22, BOTTOM) and thus, less comfortable hours comparing to the revised temperature-based control scenario (Figure 3-22, MIDDLE).
- The south-faced residential unit (Res_44) experiences significantly more uncomfortable hours compared to the north-faced unit within the two extreme ends of the indoor temperature (below 18°C and above 28°C) especially in case of the revised temperature-based control (Figure 3-22, MIDDLE).

These natural ventilation results would seem to indicate the need for further investigation which may include:

- Examining ways to further improve the thermal performance of the building envelope
- Considering a broader ‘comfort band’ based on adaptive comfort models (e.g. 20 – 26^{o}C or 18-28°C)
- Modifying the natural ventilation schedules for window openings (as a response to indoor/outdoor temperatures), and the night ventilation schedule
- Investigating additional means of achieving thermal comfort (e.g. ceiling fans)
- Evaluating the design and control options for a hybrid (mixed-mode) building (natural ventilation + mechanical HVAC)
- Determining the energy implications (energy consumption, peak demand, renewable energy utilisation) and resilience of these options.

3.2.4.6 *Key learnings for IDS*

Two key learning emerge from this parametric energy/thermal comfort simulation and optimisation case study:

1. Co-designers in an integrated design studio, should be encouraged to apply parametric design thinking at early stages of project design because it helps participants to understand the impact of each design scenario on the targeted environmental aspects, and can therefore assist their decision-making processes to be efficiently constructive

2. Parametric analysis also enables clients to identify the most energy-efficiency and cost-effective design solutions based on the project budget. This means clients can inject a wider set of project criteria into the design stage, from building energy performance to economic aspects.

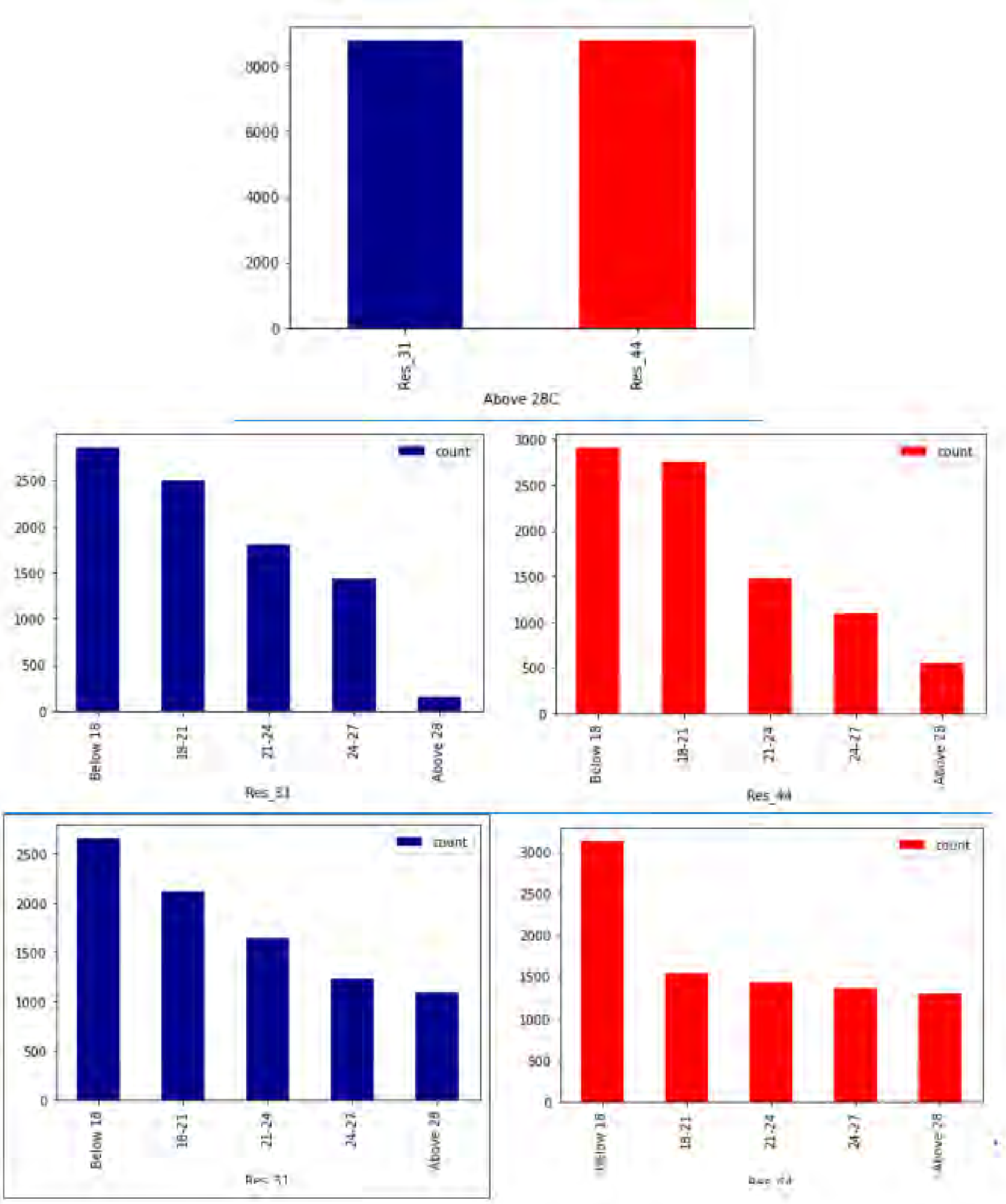


Figure 3-22 Example of temperature-based control comparison with (TOP) and without (MIDDLE) maximum indoor temperature condition, and night-time natural ventilation (BOTTOM)

3.3 Summary of technology options and impacts

Section 3 has shown that there are a range of design and technology solutions that can reduce energy demand and/or increase the renewable energy potential for mixed-use buildings (incorporating aged care) in the sub-tropics. A summary of the findings of the technologies evaluated in this IDS13 is shown in Table 3-10. Note that these indicative savings are based on the specific assumptions for each of the feasibility assessments. It should also be noted that technology solutions examined for IDS14 (for the tropics) and for other IDS projects (in temperate climates) may also be suitable for the subtropics and for this mixed-building typology.

Table 3-10 Summary of technology options and impacts - sub-tropics

Technology	Indicative demand reduction potential (compared with BAU)	Renewable Energy Potential	Co-Benefits
Vertical Green Systems	20-44% reduction in cooling energy	Would increase the % of load met by PV	Increase thermal comfort; health and environment benefits; dementia benefits
Adaptive Design	-	-	Lower embodied energy over life of the building
PV + Battery with Supercapacitor	Potential to participate in demand response markets	360kWp could meet NZE 8*50kWh battery storage could be beneficial	
Parametric design – for materials selection	>10% reduction in cooling demand	Would increase the % of load met by PV	
Parametric design – for natural ventilation and control strategies	A process to enable quantification of reduction in cooling load		33% increase in indoor comfort Potential for optimal performance outcome within the cost parameters required

4 EVALUATION OF INTEGRATED DESIGN PROCESS

4.1 IDS key learnings

Five main factors were identified through the IDS13/14 process that are key to implementing integrated design. These factors, shown in Figure 4-1, are interrelated and interdependent. Some of the key issues, associated with each factor, are further explained below.

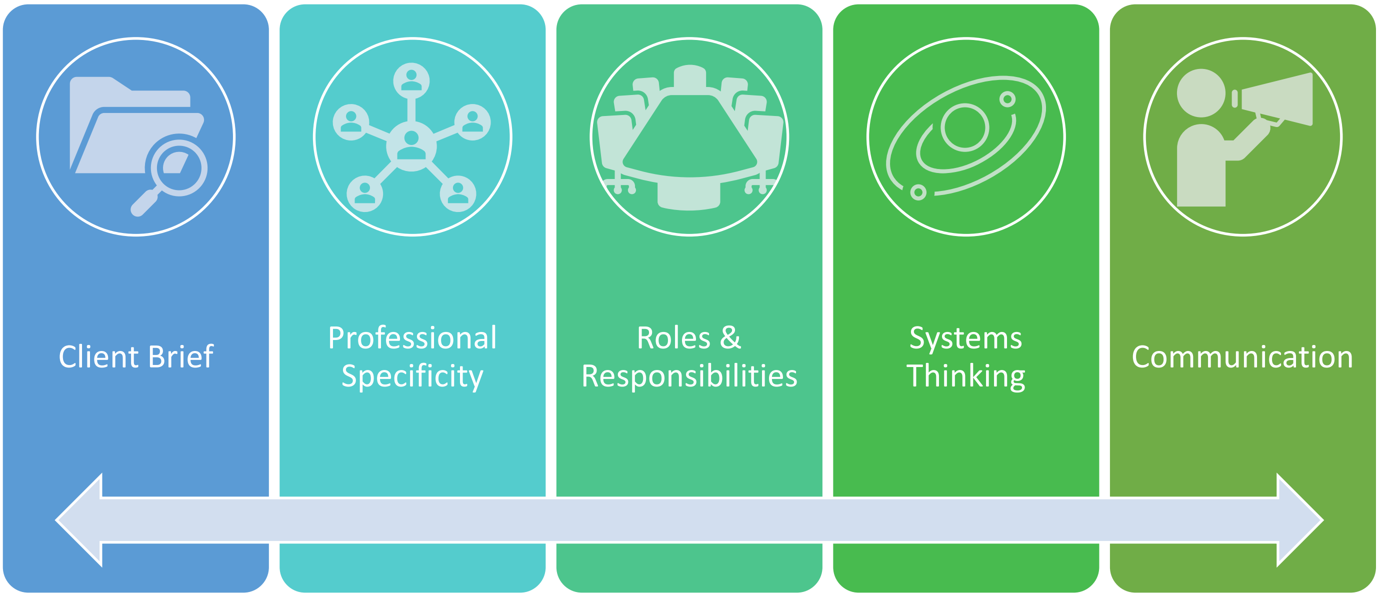


Figure 4-1 Five factors influencing IDS success

4.1.1 Client Brief

In current practice, the nature of the information provided by the client differs for each recipient, i.e. architects receive different information to engineers who receive different information to construction contractors. This is likely because of the current linear approach to design, with more and more detail provided as different professions are included in the process as it progresses. Each profession, as it engages in the process, adds more technical detail to the brief. This linear approach could be a barrier to creativity and innovation, particularly in the context of a rapidly changing environment with regard to energy technologies, carbon reduction requirements and a changing climate. It can also lead to significant rework, cost overruns and perverse outcomes (refer to Table 4-1). One could argue that having an Integrated Design process for the development of the initial brief would be beneficial in optimising design and implementation outcomes. Client inputs, at this very early stage, could include things such:

- purpose of the building (e.g. building classes; nature of occupants; occupancy times)
- general goals (social, environmental, economic)
- risk appetite (e.g. what Technology Readiness Level will proposed solutions need to meet)
- financial expectations (e.g. return on investment)
- the time span for considerations (e.g. does the client intend to own and operate the building? Over what time period? Are changes in building use possible over that time period?)
- any corporate, shareholder and regulatory reporting requirements

4.1.2 Roles and Responsibilities

A key component of an Integrated Design Studio is the recognition, acceptance and enabling of each participant to be a co-designer (as opposed to, for example, technical consultant subservient to designers). This will require, however, the assembled team to discuss and agree on decision making processes. This is likely to require a new role – that of an IDS coordinator or facilitator, possibly an independent third party who can facilitate the process in a neutral manner. This role would potentially suit an experienced project manager with an IDS background and/or a 'systems integrator' with excellent communication and collaboration skills and a firm grasp of social, environmental, economic and technical issues.

4.1.3 Professional specificity

The rich complexity of a building, within the context of net zero energy goals, requires a transdisciplinary team to cross-pollinate ideas and foster creativity. Bringing such a team together, however, may require providing opportunities for each participant to understand the terminology, thinking and design processes, and specific tools used by disciplines outside of their own. In this IDS, there was initially little knowledge of (and hence appreciation for) the role of energy modelling professionals, sustainability consultants and construction managers. In addition, designers and engineers often don't know what they don't know and are limited by previous knowledge and experience. This can lead to re-using previous solutions or designs or assumptions. The ID process should question these preconceived approaches and start with a clean slate. It can do this through creating a space for innovation and sharing, without the constraints of having to produce an output immediately.

4.1.4 Systems thinking

This relates not only to understanding the complexity of the energy system (e.g. the climate, building envelope, HVAC technologies, renewable energy technologies and the broader electricity grid and markets), but also understanding and designing for building occupants (e.g. how the energy system solutions impact on indoor environment quality and occupant health and wellbeing).

4.1.5 Communication

A range of communication strategies and mediums is required to support, encourage and challenge design ideation; to effectively exchange information; and to develop respect, earn trust, promote vulnerability and openness, and demonstrate accountability. Non-verbal, verbal, written, graphic and digital mediums will be required, in both formal and informal communications. Active listening and critical inquiry are essential.

4.2 Application to industry

To encourage the application of the Integrated Design Process (IDP) in industry conceivably requires two key things: a procurement contract that enables IDP to take place, and a set of principles to guide the IDP. This section proposes ways forward for both of these aspects.

4.2.1 Contracting for IDS

In common practice, contractors (construction companies) can be engaged in the design process under several different procurement options, such as Early Contractor Involvement (ECI) or Design and Construct (D&C) contracts. Under these contracts a level of design has already been undertaken previously, and the client brief to these contractors includes principal project requirements (PPRs). It is up to the construction company to relate all design works back to the PPR; collaborate with the client and end users to gain a full understanding of the needs; analyse wants versus needs; evaluate design intent versus what is physically possible; and assess risk and opportunities.

The overall goal, of these contractors, is to ensure cost-effective value that aligns the design to achieving the best possible outcome for the client. Similar to the evolution of design that becomes more and more detailed over time, cost planning methods also differ from early-stage design to contract sum (Figure 4-2). For example, an elemental cost plan is generally based on $/m^2 for a particular type of building, using historical pricing data. This has a high level of uncertainty. An approximate quantities cost plan, at the next stage, includes trade package descriptions and rates, builder's preliminaries, and other fees and charges (e.g. consultants' and authorities' fees). Some risks and opportunities are identified.

By the time of the tender pricing, the details of the design should be advanced; 3D models created; specifications and schedules compiled; finishes specified; subcontractor pricing received; and the program of works completed. This removes a fair amount of uncertainty and lowers the risk for both builder and client. The inclusion of construction management in the IDS process under these procurement methods provides some level of risk management in optimising the cost-effective realisation of design intent.

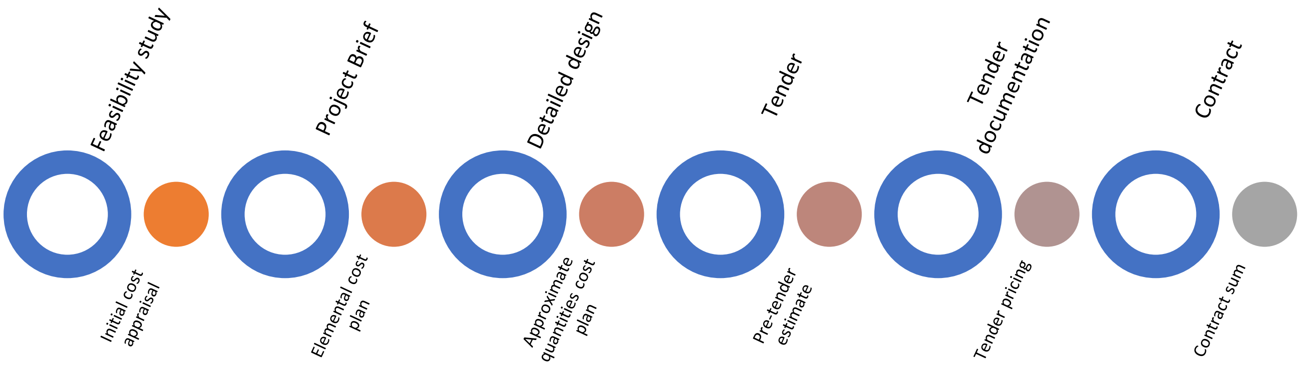


Figure 4-2 Construction major design stages (blue) and associated cost planning stages

The Integrated Design process, however, needs a different approach, one that enables construction contractors to be involved at a much earlier stage. An evaluation of three different types of contracting models is provided in Table 4-1, showing, at a high level, typical outcomes from each contracting model. From this evaluation, it appears that the third, the Integrated Project Delivery procurement model, is best suited for supporting the integrated design process, as it incorporates the client, architects, engineering and construction managers in a risk-sharing collaborative agreement from the very start of project ideation.

Table 4-1 Comparison of contracting models and outcomes

Contracting Models	Typical Outcomes
Traditional methods (e.g. fixed price contracts such as; lump sum, D&C, EPC)	• Contractor incentivised to submit a bid based on incomplete information, leading to perverse outcomes (exclusions, change orders, hidden exclusions); • Often results in cost (and time) overruns; • Parties attempt to transfer risks.
Collaborative Contracting (e.g. early contractor involvement (ECI), and managing contractor (MC))	• All parties given an incentive to see a project succeed; • Flexibility to cater for different levels of collaboration, and associated adjustments to price and risk; • Non-adversarial approach; • Shared liability; • Potential cost savings to all parties (not likely for small projects); • Contractor margins may be lower (but profit-sharing opportunity may be higher); • Contract establishment costs may be higher initially (but reduce with increased corporate learning).
Integrated Project Delivery (IDP) (In its pure form, a single, multi-party contract between owner, general contractor and designer/s)	• All parties accept, manage, and share design and construction risks; • Financial risks and rewards shared through an agreed profit/incentive pool based on quantifiable project outcomes; • Establishes individual and group accountability; • Encourages candid communication; • Cost dictates design; • Cost and design validation and optimisation happens as opportunities arise; • Coordination enhanced through use of BIM (for design coordination) and Project Management Information System (PMIS).
Sample Contracts to support Integrated Design	
NEC4 Design, Build and Operate Contract (DBO)[18]	• A contract for an integrated whole-life delivery solution; • Suitable for contracts extending into operational phase.
NEC4 Alliance Contract (an IDP type contract)[19]	• Multi-party contract for projects requiring deep collaboration between all project partners; • All partners have an equal voice; • Values shared performance instead of individual performance.

4.2.2 *Integrated Design principles*

Factor Ten Engineering, developed by the Rocky Mountain Institute, demonstrated over a decade ago that very large energy and resources savings (a factor of 10) could be profitable through transforming design and engineering practice via whole-system thinking and integrative design. The Factor Ten Engineering Design Principles have been used as a basis for developing a set of Integrated Design Principles for Net Zero Energy Buildings. The ID process allows for the optimisation of the performance of buildings, bringing together diverse teams to understand how the parts work together as a system, then turning those links into synergies that optimise the performance outcomes of the whole system.

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[18] https://www.neccontract.com/NEC4-Products/NEC4-Contracts/NEC4-Design-Build-and-Operate-Contract
[19] https://www.neccontract.com/NEC4-Products/NEC4-Contracts/NEC4-Alliance-Contract

Table 4-2 Applying Factor 10 Engineering Design Principles[20] to IDS for net zero energy buildings

Design phase	Factor 10 Engineering Design Principles	Integrated Design Principles for Net-Zero Energy Buildings
Before design starts	**1.** Define shared and aggressive goals	Establish a clear, shared, ambitious NZE goal and timeframe for achieving that goal. Consider including other related goals, such as resilience, adaptation, grid autonomy. Determine KPIs that reflect the goals, including ambitious energy efficiency.
	2. Collaborate across disciplines	Convene a transdisciplinary design team (e.g. engineers, architects, construction contractor, building owner/manager/occupants, ID specialist/facilitator) with diverse skills and experiences.
	3. Design nonlinearly	Avoid the linear march through traditional design phases (project objectives and aspirations; design concept development; master planning; design development; feasibility evaluation). ID is iterative, with successive stages informing earlier ideas.
	4. Reward desired outcomes	Implement an Integrated Project Delivery contract that rewards teams for meeting KPIs and providing savings, rather than producing documents.
Focus on the right problem	**5.** Define the end-use	Understand the purpose of the building and the needs of the people who will occupy it. What energy services will be required and what environmental, regulatory, technical and social contexts are likely to exist over this period?
	6. Seek systemic causes and ultimate purposes	Push past end-uses (e.g. HVAC), resulting services (e.g. comfort) and ultimate benefits (e.g. health, productivity) to understand the full range of ways to fulfill the purpose/s.
	7. Optimise over time and space	Take a whole-of-life approach to designs and their consequences (i.e consider current and future occupants and environmental context).
	8. Establish baseline parametric values	Establish BAU benchmarks for the KPIs, and whole-system, lifecycle value of savings (e.g. in kWh, kW, CO2e, HVAC kVa, PV kWp etc)
	9. Establish the minimum resource theoretically required, then identify and minimise constraints to achieving that minimum in practice	Use science and the plethora of simulation and modelling tools available to determine the theoretical minimum amount of energy needed to provide the energy services (especially HVAC). Consider how far each practical design constraint (e.g. cost, safety, performance, accessibility) moves away from that theoretical minimum.
Design Integratively	**10.** Start with a clean sheet	Don't start with a familiar or previous design or conventional assumptions or methods. Start afresh with no preconceptions.
	11. Use measured data and explicit analysis, not assumptions and rules	Question all rules of thumb and assumptions. Require all proposed design options to demonstrate performance against the KPIs.
	12. Start downstream	Establish a hierarchy of approaches: super energy efficient building envelope (design and materials), building services (technologies and controls), and renewable energy (generation, storage, control). This will produce compounding savings upstream.
	13. Seek radical simplicity	Simplify systems and components, valuing passive solutions over active solutions wherever possible
	14. Tunnel through the cost barrier	Think beyond current benefit:cost evaluations and minimum performance standards. Incorporate whole-of-life, total cost of ownership, and non-monetary value evaluations
	15. Wring multiple benefits from single expenditures	Create enhanced value by ensuring each part, subsystem or system provides multiple benefits.
	16. Meet minimised peak demand; optimise over integrated demand	Optimise energy systems to meet the diverse annual and seasonal conditions (use and generation), and implement control strategies to minimise or shift peak demand and optimise self-consumption
	17. Include feedback in the design	Incorporate technologies (e.g. integrated BMS, EMS) and processes (e.g. post occupancy evaluation) to inform design success and future designs.

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[20] 10xE Design Principles 1.0, Rocky Mountain Institute, August 2010

5 CONCLUSION

The combined IDS 13 and IDS 14 studios were delivered at QUT throughout 2021. The studios have involved 47 participants: 32 students from four different disciplines, four academic/professional studio leaders (architecture, engineering, and architectural engineering), six industry/professional consultants (engineering, ESD, and construction management), two client representatives, and three academic researchers.

The project implemented and evaluated a range of strategies to enhance integrated design aspects within the design of mixed-use building typologies in subtropical and tropical climates. It also fostered the development of design solutions that could reduce the carbon emissions of such buildings through reduced demand, HVAC controls and/or renewable energy and storage systems. The feasibility of some of these designs solutions has been evaluated for demand reduction, renewable energy contribution and other benefits. The key messages, from these designs and evaluations, are:

- Optimising the thermal performance of the building envelope through passive means is essential for unlocking the full value of solutions by dramatically reducing the cooling load. Parametric analysis tools are very helpful in the selection of key materials and performance characteristics to achieve this optimisation.
- Cooling loads in the subtropics and tropics can be reduced to such an extent as to open up the possibilities for a wider range of cooling technologies (e.g. radiant cooling), and/or peak load reductions, and the flow-on operational and environmental benefits from such solutions
- Renewable energy potential is then increased (i.e. the percentage of load met by rooftop PV increases), with the possibility of achieving net zero energy.

This project has also identified key aspects that support the IDS process and has proposed a procurement contract model that seems to be consistent with the intent and practice of IDS.

REWARD DESIRED OUTCOMES

"Rewarding designers just for producing documents on-schedule and on-budget elicits relabelled old designs or minor variants. But rewarding designers for what they save, not what they spend, can powerfully motivate creativity, teamwork and radical imagination. Smart reward structures encourage both risk-taking in designers' heads and practical, reliable results achieved with intelligent risk management and elegant frugality.:

Factor 10 Principle #4

6 APPENDIX A - PROJECT CONTEXT AND INITIAL FINDINGS

6.1 Bolton Clarke and the Caboolture site

The client, Bolton Clarke, is a vertically integrated not-for-profit organisation who develops, owns and operates buildings that incorporate various aspects of aged care. The client's core mission is to improve the health, independence, and quality of life of its elderly clientele. This mission must be achieved in a financially viable manner, which includes a 'whole of life' approach to building assets, and an integration of aged care facilities into the community, for example through mixed-use buildings. This section provides key information about the Caboolture site: the site redevelopment plan (Figure 6-1). Stage 1 was completed in 2020 (Fernhill Residential Aged Care). This IDS could focus on either Stage 2 or the "future development" sites within this campus. The site is on Caboolture's main road (King Street), at the edge of the town's Central Business District (commercial and government services), and adjacent to education and recreation facilities. It presents opportunities for the incorporation of other building typologies into the existing aged care campus.

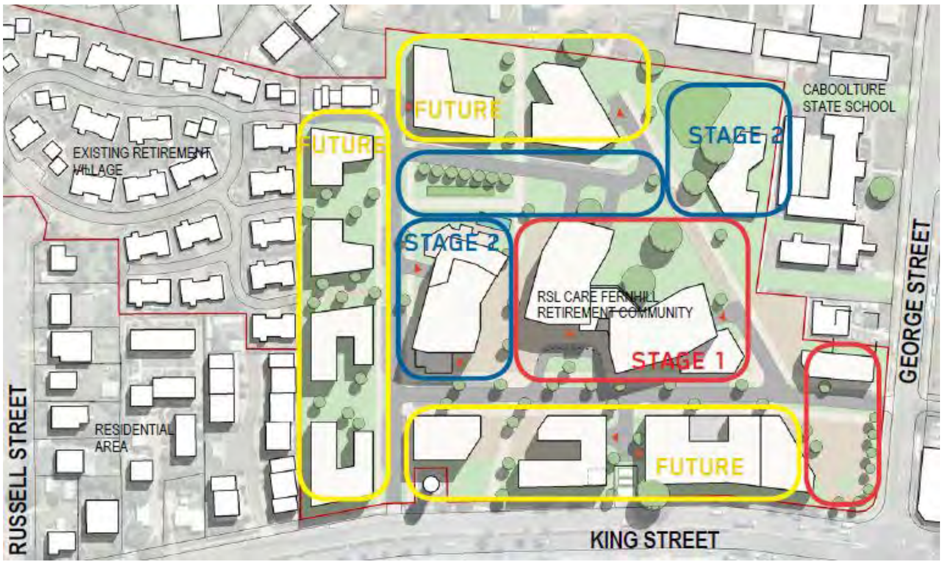


Figure 6-1 Caboolture site development plan

6.2 Studio inception

A planning meeting was held with non-student project participants prior to the first studio. This meeting, involving the client, academics and consultants, was used to establish a common understanding of the purpose, objectives and scope of the project, as well as to establish the professional relationships required to enable collaboration between all parties. Similar studio inception activities were understaken in each stage, with a focus on developing interpersonal relationships and building respect for other disciplinary knowledge:

- Stage 1 - week 1: activities to introduce the engineering and construction management students to each other and their academic guides;
- Stage 1 - week 3: introducing the client, consultants and non-architectural students and academics;
- Stage 2 - week 1: engineering and construction management students introducting themselves and their discipline interest to architecture students; and
- Stage 2 - week 2: introducing the client to the architecture students; and introducing the design thinking process to non-architecture students.

6.3 Client engagement and constraints

Bolton Clarke was open to innovation and creativity in terms of building typology (mixed use), building form, building materials and energy technologies, and did not wish to impose its current practices and perceptions on solution ideation. This openness, however, came with four key constraints regarding technology and design solutions:

- Proposed solutions needed to be proven (not experimental or emerging);
- Proposed solutions needed to show a return on investment (not necessarily financial; life-time cost of ownership was important, as was any quantification or qualification of additional non-financial benefits, e.g. health and welfare of occupants);
- Proposed solutions needed to consider and take into account the effect on elderly residents; and
- Proposed solutions needed to conform to environmentally sustainable design (ESD) principles adopted by Bolton Clarke. Net-zero energy is not currently a goal of the client.

The client was involved in the concept development of the studio, and at key points during both stages: presenting a project brief (stage 1 and stage 2); responding to questions about the brief; providing feedback on early concept development; and evaluating final design solutions.

6.4 Design studio program

Note that this section is the same for both IDS 13 and IDS 14.

6.4.1 Objectives of this interdisciplinary collaborative design process

The objectives of this IDS process were to produce innovative and detailed design solutions that:

- Are people-centred, improving residents' health, independence and quality of life, taking into account nine priority dimensions (Figure 6-2);
- Integrate technical and functional performance and 'constructability' with the many other design aspects of mixed-use buildings (Figure 6-3);
- Appropriately address the tropical and sub-tropical climatic contexts (Figure 6-2 and Figure 6-3);
- Demonstrate understanding of architectural, engineering and construction interdependencies resulting in prioritisation of passive solutions over mechanical and electrical solutions;
- Present an integrated systems approach to energy services that considers the:
    - Competing needs of building occupants (at any one time and over the life of the building),
    - Provision of energy services, energy supply and demand technologies and profiles, and
    - Interactions with other buildings, the electricity grid and the energy market;
- Enable flexible management of cooling demand and optimisation of renewable energy, as a step towards (near) net zero energy buildings; and
- Evaluate proposed solutions from a whole-of-life perspective that includes constructability, operation, maintenance, refurbishment and end-of-life (Figure 6-4).

Figure 6-2 Nine Priority Dimensions for Aged Care Design (Source: Burton, Iftikhar, 2021)

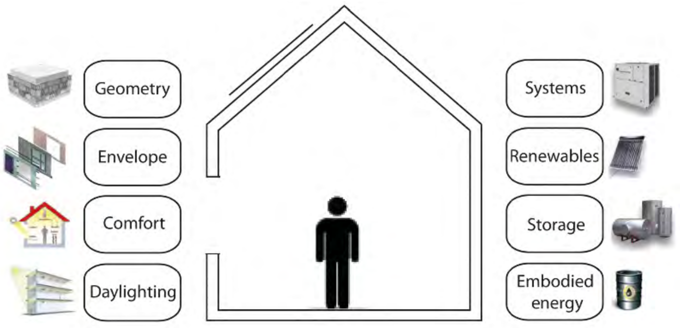


Figure 6-3 Architectural, engineering and construction interdependencies

(Source: Modelling, Design and Optimisation of Net-Zero Buildings, 2015)

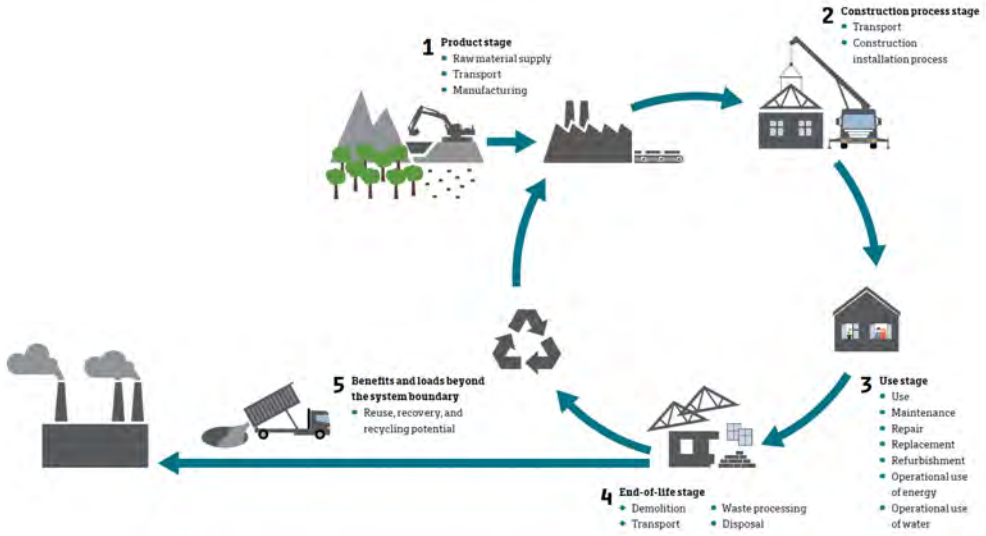


Figure 6-4 Whole of life considerations (Source: Introduction to LCA of Buildings, 2016)

6.4.2 Set up for collaborative design integration

The IDS 13 and 14 programs expanded previous IDS processes by adding sustainability and construction management domains into the process. They provided a low-risk environment for emerging professionals and seasoned professionals from multiple disciplines representing the design-construct process of a building. This mixed-discipline, mixed-experience team worked collaboratively on common goals whilst closely observing the key moments/instances that lead to integrated design outcomes. As with the initial IDS projects, the intent of IDS 13 and 14 is to examine how early career and experienced professionals engage in both the process and outputs of strategic co-design. This IDS structure incorporated the six levels of learning as presented in the modified Bloom's Taxonomy: remember, understand, apply, analyse, evaluate and create.

IDS 13 and 14 were operated in conjunction (because of the same client) and in separate groups (because of the differences in climatic and site contexts). The projects consisted of the bringing together of final year engineering and construction management honours students (4th year emerging building services and construction professionals undertaking their thesis project over two semesters), Master of Architecture students (5th year emerging designers undertaking their studio requirement over one intensive semester), experienced practitioners in the same fields, and academics with industry and research expertise.

This report presents activities relating to the joint activities and preliminary outputs relating specifically to the Caboolture (sub-tropical) context.

6.4.3 Integrated Design Process development

The IDS process was undertaken in 2 stages to optimise the involvement of early-career non-architecture disciplines with minimal design experience. Stage 1 represented real-world practice where emerging professionals in mechanical or electrical engineering, and in construction management, are incorporated into a consultancy via a graduate program or similar. These young professionals learned about the nature of the profession from more experienced professionals, and also how non-architecture consultancies are integrated in building design and construction projects. This knowledge and understanding were expected to develop over time, to enable future participation in integrated design projects (e.g. when an engineering consultancy, construction management company and architecture firm combine with a client on a specific brief.) Table 1 outlines the development of knowledge and understanding of these emerging professionals (the first two stages of Bloom's Taxonomy). This approach enabled them to contribute to the co-design workshops with architecture professionals and emerging practitioners more successfully, in stage 2.

Stage 1 participants joined emerging and practicing architects in Stage 2 to develop integrated solutions that responded to the client brief and IDS objectives. Stage 2 incorporated different studio types (e.g. co-design workshops and strategic workshops), with a range of activities to test and evaluate strategies for enhancing the co-design process. Stage 2 outputs were expected to be detailed design solutions (from the architecture students) and detailed technology specific reports (from the engineering and construction management students). The Stage 2 process is shown in Table 2. Note that the activities in the shaded cells are yet to be undertaken. They will be presented in the final IDS report (milestone 7).

The total student participants of the IDS 13 and 14 included:

- 26 Master of Architecture Students (13 students for the Caboolture project);
- 2 Bachelor of Electrical Engineering students (1 for the Caboolture project);
- 1 Bachelor of Mechanical Engineering student (None for the Caboolture project); and
- 3 Bachelor of Urban Design (Construction Management) students (1 for the Caboolture project).

Academic leads and consultants worked across both project contexts (Cairns and Caboolture), whereas student participants selected one site context on which to focus their design solution.

The IDS concurrently managed both student academic outcomes, as well as IDS project outcomes, both within the context of the client brief and with the participation of a multidisciplinary team of co-designers (Table 6-3).

Table 6-1 Stage 1 Development of knowledge and understanding (non-architecture participants)

Week	Studio type	Learning Activities
1	Co-design workshop (engineering and construction management students, and academics)	• Introduction to project • Relationship building • Mind maps
2	Co-design workshop (engineering and construction management students, and academics)	• Background research
3	Combined Workshop (client and ENG/CM students, professionals, and academics) **FOCUS: Understanding the client brief and building users** • Relationship / Trust building	
4	Co-design workshop (engineering and construction management students, and academics)	• Topic investigation
5	Combined Workshop (client and ENG/CM students, professionals, and academics) **FOCUS: Discussion forum on health and sustainability** • Presentations on Air Quality and Health; Energy Efficiency; Thermal Comfort; Building Simulation; Sustainability Rating Schemes • Discussion regarding implication for IDS process • Padlet: implication for the 2 design sites	
6	Co-design workshop (engineering and construction management students, and academics)	• WELL Building Standard
7	Combined Workshop (client and ENG/CM students, professionals, and academics) **FOCUS: Climate / HVAC / energy modelling**	
8	Co-design workshop (engineering and construction management students, and academics)	• NABERS / Green Star
9	Combined Workshop (client and ENG/CM students, professionals, and academics) **FOCUS: Construction management, project management, cost estimation**	
10	Co-design workshop (engineering and construction management students, and academics)	• Pragmatic solutions
11	Combined Workshop (client and ENG/CM students, professionals, and academics) **FOCUS: How to evaluate options; Integration**	
12	Co-design workshop (engineering and construction management students, and academics)	• Own work; academic / group feedback
13	• Student presentations of early research / analysis / design ideas	
15	• Student presentations (Engineering) to broader engineering group	
Post-semester	• Reflective Workshop (capture the IDS process learnings)	

Table 6-2 Stage 2 IDS application, analysis, evaluation, creation (all participants)

Week	Studio type	Learning Activities
1	Co-design Workshop (all students / academics)	• Meet and greet • Existing perceptions of climate, age, energy • Non-architecture early design idea • Understanding old age
2	Strategic Workshop (all participants) **FOCUS: Client brief** • Relationship and trust building • Client brief (interview / Q&A) • Understanding the 9 design principles	
3	Own work (public holiday)	
4	Strategic Workshop (all participants **FOCUS: Analysis of sites/users and functional agenda** • Developing empathy • Feasibility analysis of early ideas • Understanding the 9 design principles	
5	Co-design Workshop (all students / academics)	• Early design ideas
6	Co-design Workshop (all students / academics)	• Schematic design ideas; concept plan
7	Presentation of concepts to client and feedback	
8	Strategic Workshop (all participants) **FOCUS: Integration** • Design development: discussion and critique	
9	Co-design Workshop (all students / academics)	• Finalisation of schematic design
10	Strategic Workshop (all participants) **FOCUS: Feasibility (evidence to support viability of solutions)** • Design development: discussion and critique	
11	Co-design Workshop (all students / academics)	• Design development: detailing
12	Co-design Workshop (all students / academics)	• Design development: detailing
13	Co-design Workshop (all students / academics)	• Finalise design / reports • Revisit perceptions
14	Reflective Workshop (capture IDS process learnings)	
15	Presentation of design solutions to client, consultants and academics	
Post semester	Selection of 4-6 design solutions for each site Feasibility Assessment / Vetting of selected design solutions	
	Evaluating IDS process and outputs	

Table 6-3 Academic and Industry Co-Designers and IDS Project Researchers

Role	Name and Key Responsibility	Specialty
Project Managers	Associate Professor Wendy Miller (overall program) Associate Professor Lindy Burton (IDS research process, outputs, industry application)	Systems thinking; buildings; energy Architectural professional practice; BaSE Mindset; health architecture
Project Research Fellow	Dr Naima Iftikhar	Architectural professional practice; Architectural pedagogy
Studio Leads (architecture)	Adjunct Professor Paul Trotter (guide architecture students) Adjunct Professor Mark Trotter (guide architecture students)	Architectural Practice (professional) Architectural Practice (professional)
Academic Leads (non-architecture)	Dr Aaron Liu (guide engineering students) Dr Sherif Zedan (guide construction management students)	Electrical engineer; renewable energy Architectural engineer; energy modeller; stakeholder management
Client **(Bolton Clarke)**	James Mantis (Client representative) James Chiou (Client brief)	Asset management Project management
Consultants / Co-designers	Tian Song, JHA Engineering	Mechanical engineer (professional)
	Patrick Chambers, Stantec Australia	Mechanical engineer (professional)
	Nikki Parker, NDY	Energy modelling / ESD (professional)
	Andrew Williams	Energy modelling / ESD (professional)
	John Tuxworth, BEC	Construction, performance ratings (professional)
	Scott Butler, Hansen Yuncken	Construction Management (professional)

6.5 Preliminary findings

6.5.1 Stage 1 Observations

6.5.1.1 Roles within the studio

There were three main roles within this stage: *early career co-designers* (engineering and construction management students with no previous professional building design experience); *academic co-designers* (responsible for guiding the students and for contributing to design ideation based on their academic and professional/industry experience); and *experienced professional/industry co-designers* (responsible for sharing knowledge and experience about building services and sustainability within the general design and construction context, and the specific aged care and mixed use building context).

6.5.1.2 The Client Brief

The role of the client was to provide the context for all co-designers (early career and experienced). The client brief was not as detailed as what would typically be presented for architects, to facilitate and support creative design ideation. This brief was more of an introduction to the company (Bolton Clarke) and its goals and objectives; its current projects (involving innovation and mixed-use typologies); and a broad introduction to the site context (Fernhill, Caboolture). This was done through a mixture of PowerPoint presentation, video and Q&A.

6.5.1.3 Understanding professional specificity

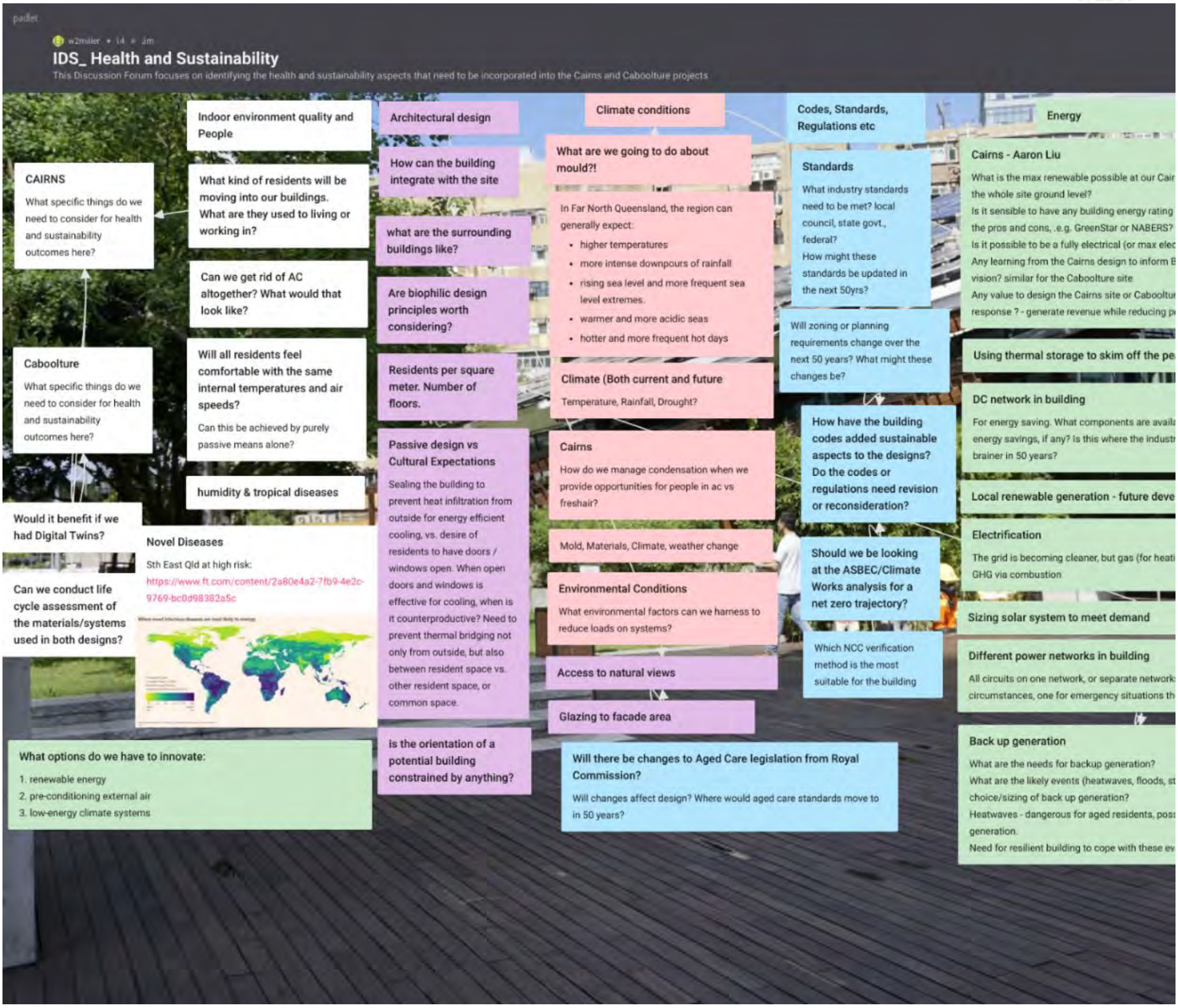
Because the early career co-designers had not been academically engaged in a design studio previously, it was important that they be exposed to the specific roles and responsibilities undertaken by different construction professionals. In particular, mechanical engineering and sustainability co-designers discussed their role in understanding the climatic context as it impacts on occupants and building services; modelling the thermal performance of the building envelope (to determine the cooling and heating load); and designing an appropriate HVAC system. The construction management co-designer discussed his role in project management and practical considerations in the implementation of construction and building services onsite. It was important to expand the 'professional specificity' beyond architects and engineers, to explicitly include building modelling professionals; sustainability professionals; and construction and project management professionals.

6.5.1.4 Emergence of systems thinking and ideation

A key activity of stage 1 was a workshop exploring the links between health and sustainability (including carbon emissions from energy use). As shown in Table 3-1, this workshop commenced with an industry presentation on air quality and health; energy efficiency; thermal comfort; building simulation; and sustainability rating schemes. This led to a discussion on the implication of systems thinking for the IDS process. Participants used on online ideation platform (Padlet) to present their ideas. Issues and ideation emerged in 5 key themes as shown in Figure 6-5: (1) indoor environment/health (white); (2) architectural design (purple); (3) climatic context (pink); (4) energy issues (green); and (5) legislation and codes (blue). Because there were no architects or architectural students involved in this stage, early career co-designers gravitated towards specific areas of focus for their core thesis:

- Renewable energy systems and storage (electrical engineers);
- Cooling systems (mechanical engineer); and
- Green walling systems, embodied energy, and material performance (construction management).

The intent was that these students would become "subject matter experts" that could contribute to integrated design solutions with the architecture co-designers in stage 2.



padlet

w2miller • 14 • 3m

IDS_ Health and Sustainability

This Discussion Forum focuses on identifying the health and sustainability aspects that need to be incorporated into the Cairns and Caboolture projects

CAIRNS
What specific things do we need to consider for health and sustainability outcomes here?

Caboolture
What specific things do we need to consider for health and sustainability outcomes here?

Would it benefit if we had Digital Twins?

Can we conduct life cycle assessment of the materials/systems used in both designs?

Indoor environment quality and People

What kind of residents will be moving into our buildings. What are they used to living or working in?

Can we get rid of AC altogether? What would that look like?

Will all residents feel comfortable with the same internal temperatures and air speeds?
Can this be achieved by purely passive means alone?

humidity & tropical diseases

Novel Diseases
Sth East Qld at high risk:
https://www.ft.com/content/2a80e4a2-7fb9-4e2c-9769-bc0d98382a5c

What options do we have to innovate:
1. renewable energy
2. pre-conditioning external air
3. low-energy climate systems

Architectural design

How can the building integrate with the site

what are the surrounding buildings like?

Are biophilic design principles worth considering?

Residents per square meter. Number of floors.

Passive design vs Cultural Expectations
Sealing the building to prevent heat infiltration from outside for energy efficient cooling, vs. desire of residents to have doors / windows open. When open doors and windows is effective for cooling, when is it counterproductive? Need to prevent thermal bridging not only from outside, but also between resident space vs. other resident space, or common space.

is the orientation of a potential building constrained by anything?

Climate conditions

What are we going to do about mould?!

In Far North Queensland, the region can generally expect:
- higher temperatures
- more intense downpours of rainfall
- rising sea level and more frequent sea level extremes.
- warmer and more acidic seas
- hotter and more frequent hot days

Climate (Both current and future
Temperature, Rainfall, Drought?

Cairns
How do we manage condensation when we provide opportunities for people in ac vs freshair?

Mold, Materials, Climate, weather change

Environmental Conditions
What environmental factors can we harness to reduce loads on systems?

Access to natural views

Glazing to facade area

Will there be changes to Aged Care legislation from Royal Commission?
Will changes affect design? Where would aged care standards move to in 50 years?

Codes, Standards, Regulations etc

Standards
What industry standards need to be met? local council, state govt., federal?
How might these standards be updated in the next 50yrs?

Will zoning or planning requirements change over the next 50 years? What might these changes be?

How have the building codes added sustainable aspects to the designs? Do the codes or regulations need revision or reconsideration?

Should we be looking at the ASBEC/Climate Works analysis for a net zero trajectory?

Which NCC verification method is the most suitable for the building

Energy

Cairns - Aaron Liu
What is the max renewable possible at our Cair
the whole site ground level?
Is it sensible to have any building energy rating
the pros and cons, .e.g. GreenStar or NABERS?
Is it possible to be a fully electrical (or max elec
Any learning from the Cairns design to inform B
vision? similar for the Caboolture site
Any value to design the Cairns site or Cabooltu
response ? - generate revenue while reducing p

Using thermal storage to skim off the pe

DC network in building
For energy saving. What components are avail
energy savings, if any? Is this where the industr
brainer in 50 years?

Local renewable generation - future deve

Electrification
The grid is becoming cleaner, but gas (for heati
GHG via combustion

Sizing solar system to meet demand

Different power networks in building
All circuits on one network, or separate network
circumstances, one for emergency situations th

Back up generation
What are the needs for backup generation?
What are the likely events (heatwaves, floods, st
choice/sizing of back up generation?
Heatwaves - dangerous for aged residents, poss
generation.
Need for resilient building to cope with these ev

Figure 6-5 Systems-thinking themes emerging from health and energy workshop

6.5.1.5 Feedback from participants

A reflective workshop was held at the end of this stage, to capture the experiences and perspectives of all participants. This section reports on five key areas revealed in this workshop.

6.5.1.6 Goals and benefits

The goals of the project revolved around energy reduction and renewable energy targets (the goals of the iHUB project), in addition to the goals of the client. This involved working with key stakeholders on solutions within the limitations set by the client:

- Design must be based on existing, commercially available technology;
- Design must provide a return on investment (not necessarily restricted to economic return);
- Design must account for effect on aged residents, especially those with dementia; and
- Design must conform to environmental sustainability design (ESD) principles, including embodied and operational carbon.

This required developing an understanding of the project brief (e.g. site information, sustainability drivers, costs) and the roles that different professions could play in design solutions.

The benefits of this stage were identified as:

- Knowledge sharing and discourse;
- Collaboration across disciplines and between teaching, future of industry and current industry;
- Consolidation of several ideas into a practical and improvised process;
- Learning from the expertise of others;
- Consideration of role of indoor air quality in response to the pandemic; and
- Employability and networking opportunities (from students' perspectives).

6.5.1.7 Process strategies

A range of strategies were utilised during the process, each having a different purpose.

- *Mind maps* were used by students and academics to explore the project brief and consider real-world ideas about buildings in tropical and sub-tropical climates. The mind maps were discussed further in relation to individual students' projects (providing ideas about project scope).
- *Active questioning* (group) and *research* (personal) were used to provide further insights into the client's brief, development agenda and specific site constraints; and consideration of these alongside iHUB stakeholder objectives.
- *Technical presentations* (by industry) on ESD rating tools (e.g. NABERS, Green Star, WELL) and energy simulation tools, *and discussions* on their role in quantifying and optimising performance outcomes.
- *Presentations to client* (by students) on early and developing ESD strategies and ideas.
- *Discussion Forum* and *Collaborative Bulletin Board* (Padlet) were used to explore the links between health and sustainability, incorporating ideas on energy demand, HVAC, air quality, comfort and health. The focus of this strategy was on identifying co-benefits (multiple benefits of single solutions).
- *Individual feedback* was provided by academics and consultants to the students, enabling development of project drafts and refinement of focus of their project for ESD and net zero energy outcomes.
- *Industry sharing real world experience (*e.g. case study on RAC project, incorporating key learnings about project management, construction management and cost estimation; application of life cycle assessment; low energy design).

6.5.1.8 New knowledge uncovered

Student participants reported a range of new knowledge (for them) acquired during stage 1 of the IDS (Figure 6-6).

Note: students continued to build on this knowledge during stage 2, to undertake assessment of some of these topics, and to communicate this knowledge to architecture co-designers.

Electrical

- Area required for PV to meet 100% renewable electricity onsite
- Climate impacts on PV output
- Sustainable PV investment
- Passiv Haus techniques for reducing electrical loads
- Load management and system resilience
- DC microgrid

Mechanical

- Energy recovery systems
- Energy and heat minimisation strategies
- Climatic constraints of different cooling technologies
- Natural ventilation initiatives
- Pre-conditioning for humidity control and indoor air quality management

Construction management

- Green wall systems to reduce temperatures and provide HVAC benefits
- Embodied energy of construction materials
- Role of construction materials in impacting thermal performance of the building envelope

Sustainability

- Feasibility and operational benefits of optimising building envelope to suit climate context
- Embodied energy
- Modelling and rating tools and programs
- Indoor environment quality (health impacts)

Figure 6-6 New knowledge acquired by students in stage 1

6.5.1.9 Opportunities and challenges

Opportunities and challenges were perceived by students, academics, and consultants, as summarised in Table 6-4. The common challenges faced by all three groups of participants were time, and the breaking down of discipline and experience barriers. The common opportunity was the interdisciplinary collaboration and collegiality (developed over time) that resulted in the sharing of knowledge and ideas.

Table 6-4 Opportunities and Challenges from IDS Stage 1

Opportunities	Challenges
Students	
• To work with multiple disciplines and different experience levels and backgrounds for a rich input on projects; • Encouragement from teachers and consultants on students' ideas/voices; • Refining the research focus and information gathering based off professional feedback; and • Gaining an insight about the collaborative process of project meetings to satisfy a client's brief.	• At the beginning and majority of the semester for the IDS process, different professions were grouped according to disciplines; • Less contact time with industry consultants; • Limited industry knowledge, by students, as certain concepts considered simple for consultants were new for student; and • A field trip would have helped students.
Academics	
• A risk-free environment (no risks in making mistakes); • Interactive discussions; • A student gained employment through this IDS stage (real-world impact); • Aspects considered for future collaboration; • Exploration of proven technology for sustainability outputs; • Overcoming students' fear of trying something new; • Real-world authentic learning experiences; and • Generous sharing of ideas and feedback from consultants.	• Lack of quantitative analysis due to lack of actual building designs; • Getting students to engage with consultants; • Getting students to focus on activities outside of the deliverable scope (i.e. assessment scope); • Time constraints in schedule for students to identify their topics without accumulating knowledge; and • Little discussion with client about the feasibility of topics.
Consultants	
• Collegial response; • Early involvement of engineers in the process; • Sharing of ideas between disciplines and levels of experience and knowledge; • Clear defined expectations and roles; • Educate clients on benefits about design disciplines earlier collaboration in the design process; and • Small working groups that promote equal participation from student/consultant/teacher to explore selected topics through a multidisciplinary collaboration.	• Time; • No architectural form; • Students needing to choose topics before learning about them; • Roles were perceived as 'students' versus 'consultants'; • Commercial objectives of client; • Green is considered synonymous with expensive; • Scope of the consultants' role and responsibilities during the IDS; and • Lack of understanding of each other's silos, culture and relationships.

6.5.1.10 The future of IDS in practice and pedagogy in delivering sustainability outcomes

Transdisciplinary practices in the professions/industry can provide positive results, through breaking down silos and working collaboratively, to create changes in practice-based culture, comprehension and communication. This requires an early co-operative design approach when conceiving a building design that requires sustainability performance outcomes. (Note: some procurement models are discussed and compared in Section 6.4). Other suggestions to drive IDS development and inclusion in practice and pedagogy are listed below (in no particular order):

- Government mandating of sustainability outcomes for buildings;
- A unified construction program;

- Advancement in technology such as BIM/BEM that informs all stakeholders about impacts of decisions on multiple aspects instantly;
- Assessment of future weather impact and future optimisation to accommodate the impacts must be considered;
- Utilisation of machine learning to predict the future performance under certain conditions and provide best solutions to optimise cost, energy, etc.;
- A “people first” approach with buildings acting as a means to support the healing of people;
- Equating “green design” with “affordable design” [note: this requires a whole-of-life cost and value approach and consideration of ESD as just as significant as revenue];
- Built environment must work with nature and be conceived as part of the natural environment—climate change will impact on both, and the climate catastrophe must be averted;
- Future designs must value aesthetics, resources, experiences, society, community, materials and quality of the environment;
- Introduction and education must be the first step towards change. It must involve the full lifecycle of the design team;
- Clear articulation of project ambitions is required; and
- Decision making must balance a range of components including cost, carbon, resilience, and adaptability.

6.5.2 Stage 2 Observations

The IDS-14 process was guided (curated) by two main types of workshops, studio (co-design) workshops and strategic workshops. Participant interactions during these workshops were observed.

6.5.2.1 Roles within the studio

Initially the students, academics and consultants perceived their roles distinctly as learners, teachers and industry professionals. Over time, the design studio workshops impacted students’ perceptions of roles, which enabled them to break away from the rigid identity of their roles as recipients of knowledge only, and towards critical and active participants in a co-design process. Students’ roles thus transitioned to active critical thinkers and explorers of knowledge and solutions. Academics acted as mediators between consultants and students, while being facilitators of the IDS process. The consultants were considered as expert reviewers with real-world experience, to empower students with knowledge.

6.5.2.2 Communication

Communication occurred between students; between students and academics and/or consultants; and between academics and consultants. Communication barriers were observed in the early stages in particular, due to discipline specific terminologies (e.g. unfamiliarity with terminology, and different meanings applied to terminology), as well as lack of rapport between participants who were unknown to one another. It took students (early career co-designers) 3 to 4 weeks to begin active discussions, and to confidently ask questions of the consultants, other students and academics.

Communication was not restricted to verbal gestures, but included sharing and exploration of key ideas and issues, using graphic approaches such as drawing and making, and presentation of digital images and resources. During the design studio workshops, architecture students utilised active communication and critical querying from fellow students (architecture and other disciplines), and academics. In the strategic workshops, the architecture students engaged in active listening, and received feedback from consultants (both early-career and experienced co-designers) to challenge and improve their projects. This further emphasises the initial perceived imbalances of the roles, due to expert knowledge (or lack of it) on a certain topic under discussion.

During the earlier stages of the project, when architecture students didn't have specific building masses to discuss and share, the communication focused on exploring the territories of the professions. However, as the design projects developed further in the later stages of the semester, the forms of communication extended to include graphical and digital presentation styles, as well.

6.5.2.3 Feedback from participants

Following is a selection of feedback provided by engineering and architecture students, and one of the consultant/academics:

Electrical Engineering Student:

> *"This project challenged students within their own discipline, but to also regard the other professions when attempting to implement their own design. The design of the energy generation system for net zero electrical emissions, along with onsite storage options, was a discipline specific investigation. The incorporation of other professions, all with different expertise challenged the way participants thought when approaching building design and promoted a more collaborative process over individuals."*

Electrical Engineering Student:

> *"Engineering students and construction management students were assisting [architecture students to design their buildings], by providing [our] expertise to each student that required it. This included finding the total amount of PV required for their designs to be net-zero emissions, giving recommendations on orientation and angling, along with the feasibility of any experimental panel placement that they might be interested in. This altered [my] research focus, as the IDS required each discipline to work together... [my] initial research concentrated on PV cells and hybrid storage systems ... [but the needs of architecture students meant that] the research expanded to [incorporate the requirements for] MSB's [main switch boards] and DBs [distribution boards] and generators... another student [architecture] was willing to let their design be investigated for the electrical requirements."*

Architecture Student:

> "*I am in my fifth year of the architectural degree and this studio challenged me to rethink the design process, as I have always engaged in a traditional studio model. I had to consider ESD principles, real building design systems, and their integration for a sustainable outcome for my site. All of these design challenges, coupled with rapport building and consensus building across various disciplines, refined my design development for minimising the carbon footprint."*

Consultant/Academic:

> *"Students had to deal with a whole range of new species of disciplines, and to articulate their thinking to a diverse range of professionals. The integration of consultants and client in the earlier stages of the projects, allowed the architecture students to focus on the real-world constraints of the site, and to think about how energy efficiency could be improved with consideration of long-term implications, for the future impact of the building on the occupants' comfort and health.'*

6.5.3 Lessons from studio observations

6.5.3.1 Integrated Design fostered at all phases of design development

The different phases of design development utilised different strategies or opportunities for integrated design, as elaborated upon, below.

6.5.3.1.1 Project objectives and aspirations phase

The initial process in Stage 2 (all participants in the studio), was focused on understanding the project objectives and aspirations. This phase included: introduction of the project; an explanation of the nine IDS Priority Dimensions (Figure 6-2); site allocations (for architecture students); creating site-based teams and connections between architecture and non-architecture co-designers; and understanding the client's brief, values, and aspirations for sustainability and community.

6.5.3.1.2 Design concept development phase

The design concept development phase which followed, required student co-designers to further understand the site constraints, project brief, context and community needs. This phase included: collective learning of discipline specific vocabulary and design approaches; establishing individual project briefs and methods in which co-designers contribute to individual projects; research and understanding of the technicalities of building systems and services, and ESD solutions; developing spatial layouts and mixed-use needs; consideration of specific parameters and components, which are not usually considered in the early project stages; developing a shared vision/mission for community and sustainability; goal setting; and open-ended problem solving.

6.5.3.1.3 Master planning phase

The master planning phase required the architecture students to finalise the functional aspects of spaces. This phase included: consideration of building services/systems; consultants' demonstration modelling on energy consumption and feasibility of projects and services; consensus building about ideas between stakeholders; exploring building and systems' performance parameters in specific sites/climates; developing shared vision/mission for community and sustainability; integrating the nine IDS Priority Dimensions to achieve project outcomes; and continued acquisition of technical knowledge from participants and through individual research.

6.5.3.1.4 Design development phase

Half-way through stage 2, all non-student participants (including the client) provided feedback to individual students' early design development ideas. This phase included: studio leaders (professional practising architects) presentation of their own practice and projects; expanding knowledge and skills in orientation of buildings and spatial layouts; applying passive design principles; understanding both HVAC systems and natural ventilation options (mechanical services); green screens/walls/facades and their impacts on energy efficiency; inclusive design considerations; the importance of embodied energy of materials; the application of regenerative design; the integration of renewable energy (e.g. sun and wind); water conservation considerations; and methods to reduce energy demand and carbon emissions. All co-designers were provided with opportunities to participate through asking/answering specific systems/services design queries. This phase incorporated a 'whole to parts – parts to whole' approach, with all disciplines involved in the enquiry and knowledge development.

6.5.3.1.5 Feasibility evaluation phase

This feasibility evaluation phase was not implemented as well as the earlier phases, as only fairly rudimentary evaluation was undertaken by most projects. This phase included participants asking/answering specific questions about: the feasibility of practical applications; the implementation of projects and services; and appropriate architectural and engineering solutions, for specific contexts. It also included consideration, by all parties, of the extent to which proposed design solutions were addressing the client and iHUB project objectives. While some students undertook individual feasibility assessments (e.g. sizing and cost analysis of renewable energy system; or basic climate analysis to inform passive design strategies), no architectural designs were simulated for thermal performance. This was because the designs were resolved too late in the process for this to be undertaken by consultants, and the students did not have the training to do so themselves.

6.5.3.2 *Evolving interactions between participants throughout the IDS process*

The interactions between the stakeholders also evolved as the integration process unfolded through the design phases explained in the previous section. The nature of the interactions over the entire project progressively changed, as shown in Figure 6-7. Note that “shared leadership and responsibility” and “enquiry, reflection and adaptation”, established in the early phase, continued through all the phases.

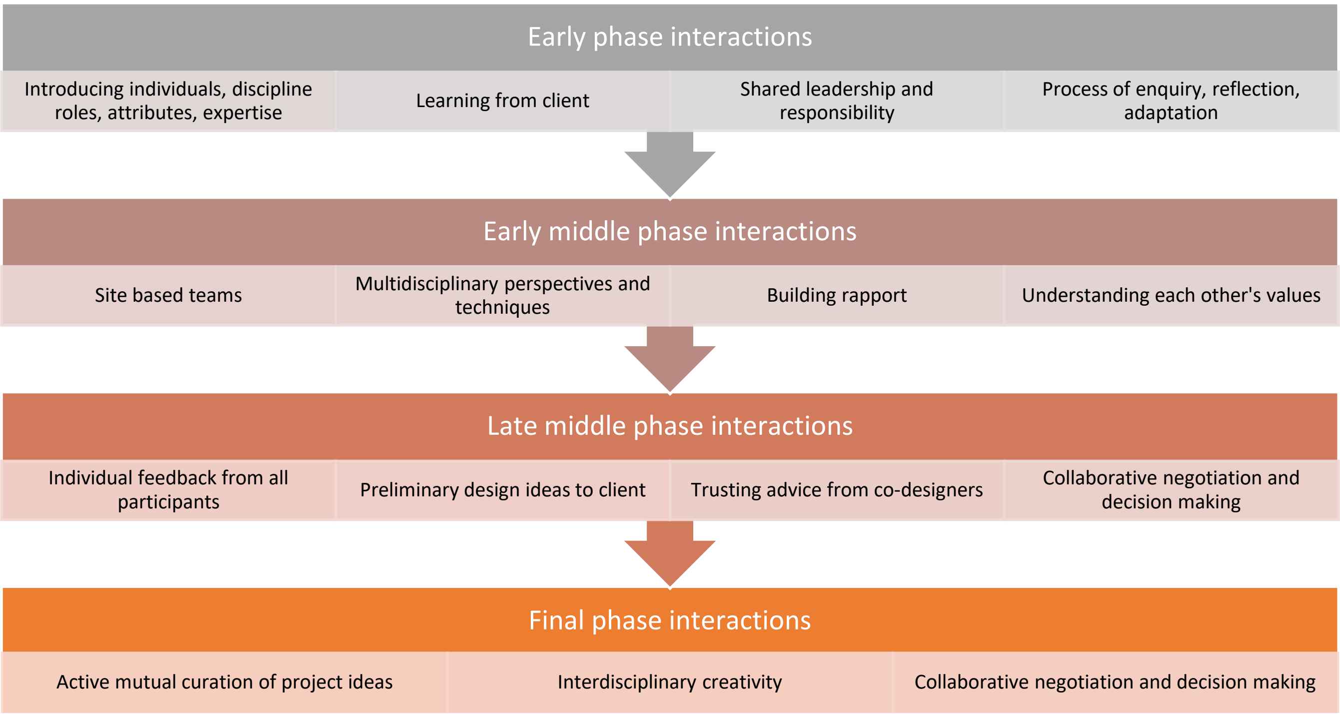


Figure 6-7 Changing nature of participant interactions

6.5.3.3 *Changing roles of participants throughout the IDS process*

The roles of the stakeholders evolved, as the process and interactions were expanded. Individual participants were, at various times, perceived as: collaborator; leader (of change/transformation of ideas); manager (of individual projects); critic; innovator; critical thinker; facilitator; learner; explorer; researcher; designer; co-designer; active curator; decision maker; and/or creator.

6.5.4 *Participant feedback*

6.5.4.1 *Optimising collaborations for different phases*

The whole-of-group collaborations actively and effectively facilitated the earlier phase of stage 2, and specifically constituted interdisciplinary groups were formed for each site context (Cairns and Caboolture). As the architecture projects progressed towards the design development phase of the buildings, individual and one-on-one collaborations were preferred, given the nature and complexity of factors emerging in individual projects. The presentations by consultants on energy modelling and specific components of building systems, enabled student collaborators to refine the focus of their individual projects. In the early to middle and end phases, there was a shift and transformation of the nature of collaborations from being scheduled and discursive to organic. This allowed the multidisciplinary teams working on similar sites to develop the individual components of their projects, in an iterative back-and-forth manner. Opportunities for collaborations were explored beyond the face-to-face mode, resulting in some teams setting up virtual collaborative places (e.g. MS Teams, Facebook groups and Google docs sharing).

6.5.4.2 Ratio of architecture and non-architecture participants

Participants noted that the ratio of the non-architecture to architecture co-designers was imbalanced (14 non-architecture co-designers (6 early-career and 8 experienced) to 26 architecture co-designers). This led to group-based collaborations, but was perceived by architecture students as impacting (negatively) on their individual project outcomes. This issue is further discussed in Section 6.1.

6.5.5 Opportunities and challenges impacting the IDS process

6.5.5.1 Opportunities

A range of opportunities were identified:

- Authentic learning opportunity, establishing a practical real-world problem-solving mindset;
- Interaction with (a real) client;
- Developing a systems-thinking approach to projects;
- One-to-one rotating meetings with consultants;
- Exploring and addressing diverse dimensions not usually considered in traditional projects;
- Detailed designs/project outcomes aligned with AIRAH/ARENA sustainability goals; and
- Professional readiness, including interdisciplinary team collaboration skills for professional practice.

6.5.5.2 Challenges

The early phases of stage 2 had three main challenges:

- Lack of an architectural design as a focus for discussions with non-architecture participants;
- Lack of knowledge or understanding on each discipline's expertise; and
- Issues relating to dealing with interdisciplinary working dynamics.

The challenges of the middle and later phases were different:

- Complexity of aspects to deal with;
- Constraints relating to time management of activities;
- Need for ongoing "lectures" from experienced co-designers about building services/systems;
- Continuing need to [remind participants] of the aspirations for sustainability and iHUB outputs;
- Lack of shared responsibility of design outputs and authorship, due to no team contracts/agreements; and
- Perceived lack of one-on-one time to consult with studio leaders, consultants and academics.

6.5.6 Value of the experience

6.5.6.1 For students

Three students gained employment as a result of participation in this IDS:

- 1 student (engineer) as an immediate part time position, and an ongoing post-graduation position with a participating consultancy;
- 1 student (engineer) as a 'graduate of engineering' position with a participating consultancy;
- 1 student (construction management) in a graduate position with a global construction company, starting in the design team responsible for coordinating onsite construction consistency, with the client brief and 'as designed' drawings.

Following is a selection of feedback provided by engineering and construction management students:

Electrical Engineering Student:

> *“After the IDS process, I feel that a better understanding of the goals and performance objectives of a vertically integrated client have been understood... The iHUB IDS project was a valuable professional experience and has given me skills and created opportunities for me that another thesis project would not have.”*

Electrical Engineering Student:

> *“This project combined an industry partner in Bolton-Clarke with a government entity in ARENA to challenge students within their own discipline, but to also regard the other professions when attempting to implement their own design. The design of the energy generation system for net zero electrical emissions, along with onsite storage options, was a discipline specific investigation. The incorporation of other professions all with different expertise challenged the way participants thought when approaching building design, and promoted a more collaborative process over individuals.”*

Construction Management Student:

> “*Thanks again for your support throughout the year and effort in providing this opportunity. I really learned a lot and enjoyed the process.*”

6.5.6.2 For university

This IDS project (13 and 14) has provided multiple benefits to QUT, including:

- Offering an authentic learning experience to participating students;
- Providing an opportunity for cross-disciplinary and interdisciplinary collaboration between students, and between schools within the Engineering Faculty;
- Further deepening of existing industry relationships and establishment of new relationships;
- Enhancing the ‘job readiness’ of graduates; and
- Potential avenues of further research (in pedagogy and in technical ESD solutions).

6.5.6.3 Future considerations for the IDS process in university settings

A number of possible options have been considered for improving the IDS implementation in a university setting.

- Incorporate aspects of IDS (e.g. interdisciplinary and multidisciplinary interaction) earlier in the engineering and built environment degree programs. This action could gradually build the knowledge and technical skills in ESD, building services and system design and evaluation processes and tools, as well as collaboration skills;
- Reserve ‘full’ IDS projects for advanced students (e.g. final year undergrad or master degree) who have pre-requisite skills and experience to contribute meaningfully;
- Revise assessment processes for these units (at all stages of the degree) to allow for, and encourage, collaborative outputs as opposed to individual outputs;
- Incorporate more architectural engineering / building science / building services into engineering, architecture and construction management degrees;
- Consider modelling collaborative work ‘contracts’ on an Integrated Project Delivery model where project members share responsibility (and risk) for the project, and allocate specific tasks and performance deliverables;
- Build a “repository” of a suite of suitable teaching and engagement resources that can be utilised for multiple purposes / units / courses;
- Foster industry relationships to continue engagement in authentic learning experiences; and
- Revisiting the process of IDS delivery to learn from experience.